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An analog system designed to make midrange regionalized forecasts is described. The analog system uses a unique historical data base which has been formulated to reduce data handling while speeding up analog matching procedures. Tuning and verification of the system are carried out for the Greater Mediterranean region. Verification results indicate that this analog system does not perform significantly better than either persistence type forecasting or forecasts produced by the current operational FNOC (Fleet Numerical Oceanography Center) analog. Possible causes for these results are discussed. ((Continued))

ABSTRACT (Continued from block 20)

Included as an appendix is a discussion of an analog-matching technique which, using the same unique historical data base, is designed to estimate the current meteorological conditions for any possible silent data area. An experiment is described which tests the adequacy of this data base to produce matching analogs for a region covering the western U.S.S.R. Results indicate that there will have to be a substantial improvement in the historical data base if acceptable analogs are to be found.

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Enclosure (1) describes an analog system designed to make midrange regionalized forecasts. Results of a verification study of this system for the Greater Mediterranean region are presented.

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A VERIFICATION STUDY OF THE IMPROVED REGIONAL RAPID ANALOG SYSTEM (IRRAS)

L. Robin Brody
Naval Environmental Prediction Research Facility

SEPTEMBER 1981

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CONTENTS

1. INTRODUCTION

Although numerical weather prediction models show considerable skill in making forecasts out to the 3 to 5 day period, there is still a need to develop methods to produce forecasts in the 1 to 2 week range. The analog method is one approach for providing these middle range forecasts.

The basic assumption made in developing an analog-type forecast is that a historical sequence can be found which evolves in a fashion similar to the current sequence: what happened in the past is a key to what will happen in the future. Fleet Numerical Oceanography Center (FNOC) currently uses an analog approach to provide forecasting aid out to 10 days.

Serious problems do exist, however, with the FNOC operational analog. Because of the large number of sizeable data records which must be searched for each analog run, large amounts of computer resources are needed. Also, the current design of the FNOC operational analog does not lend itself to optimum tailoring for operationally significant subregions. In its current design, the same basic analog run used for the whole Northern Hemisphere is simply reordered for each subregion instead of making separate analog runs for each specific subregion.

Because of the shortcomings of the FNOC operational analog, and because of the obvious benefit to be gained by improving forecasting skill for the middle range, development of an Improved Regional Rapid Analog System (IRRAS) was undertaken by NEPRF. It is the purpose of this report to give a brief description of IRRAS and its unique data base, and to describe a verification study which treated IRRAS capabilities specifically for the Greater Mediterranean subregion. A more complete description of IRRAS is found in Caton et al. (1977). Later modifications to IRRAS and a system software program description are found in Caton (1979).

2. HISTORICAL DATA BASE

The historical data base used for IRRAS consists of 30 years of FNOC analyzed grid point fields for 1946 through 1975. These analyses include both the 1000 mb and 500 mb levels, and the 500-1000 mb thickness. The pattern separation fields used for each level/thickness are SD -- small-scale disturbance; SL -- large-scale disturbance; and SV -- planetary vortex.

The method used to produce these pattern separation fields along with their interpretation is found in U.S. Naval Weather Service (1975). Examples of a 500 mb field and these three pattern separation fields are shown in Figure 1.

In order to reduce the immense size of the historical data base and to decrease computational time necessary for analog matching, a unique method has been designed for recording the pattern separation fields. This method revolves around a technique of modularizing the grid point values for each of the various pattern separation fields.

Each module is made up of a 4x4 array of grid-point values. Not all grid points are used, however, depending on which of the pattern separation fields is being considered. For the SD scale, the full density of the 63x63 grid array is used. For the SL scale, every other grid point is used. For the SV scale, only every third grid point is used. Modules for the three different scales are shown in Figures 2, 3 and 4.

A large reduction in the amount of data is then accomplished by a method of bit-coding the information for each of the modules and storing this processed information in one 60-bit CDC 6500 computer word. The composition of each word is so arranged that the first quarter of the 60-bit word gives a coarse resolution of the module pattern, the second quarter gives a medium-resolution supplement, and the remaining half word gives a fine-resolution supplement. Figure 5 shows this composition. By bit-coding the various pattern separation fields, the 30 years of analog history can be stored on one 6250 CPI 9-track tape.

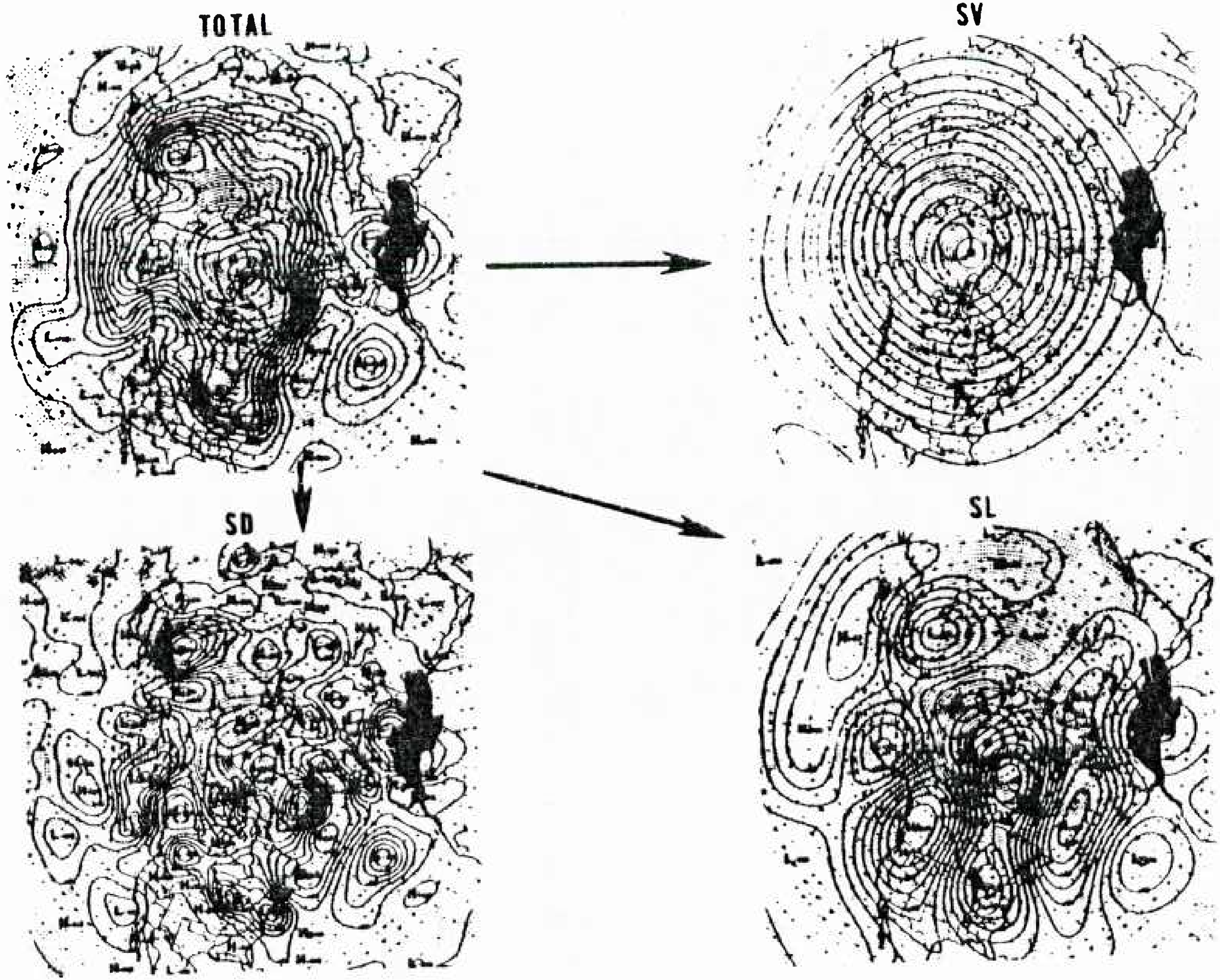


Figure 1. Example of pattern separation fields at 500 mb.

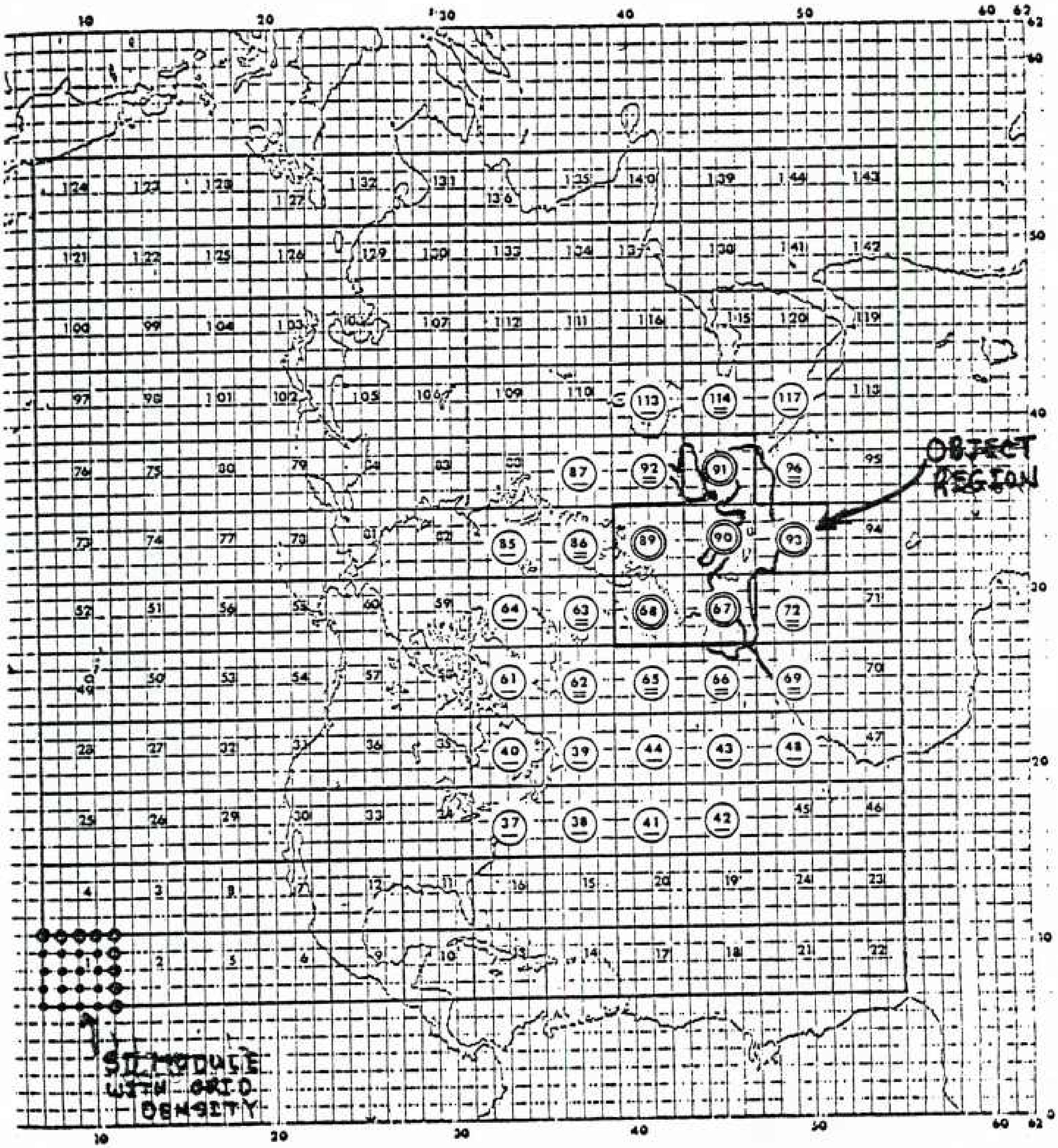


Figure 2. Greater Mediterranean focus for SD component fields. Numbered boxes indicate SD modules; resolutions indicated by

modules with coarse resolution data,

modules with coarse and medium resolution supplements,

modules with full resolution data.

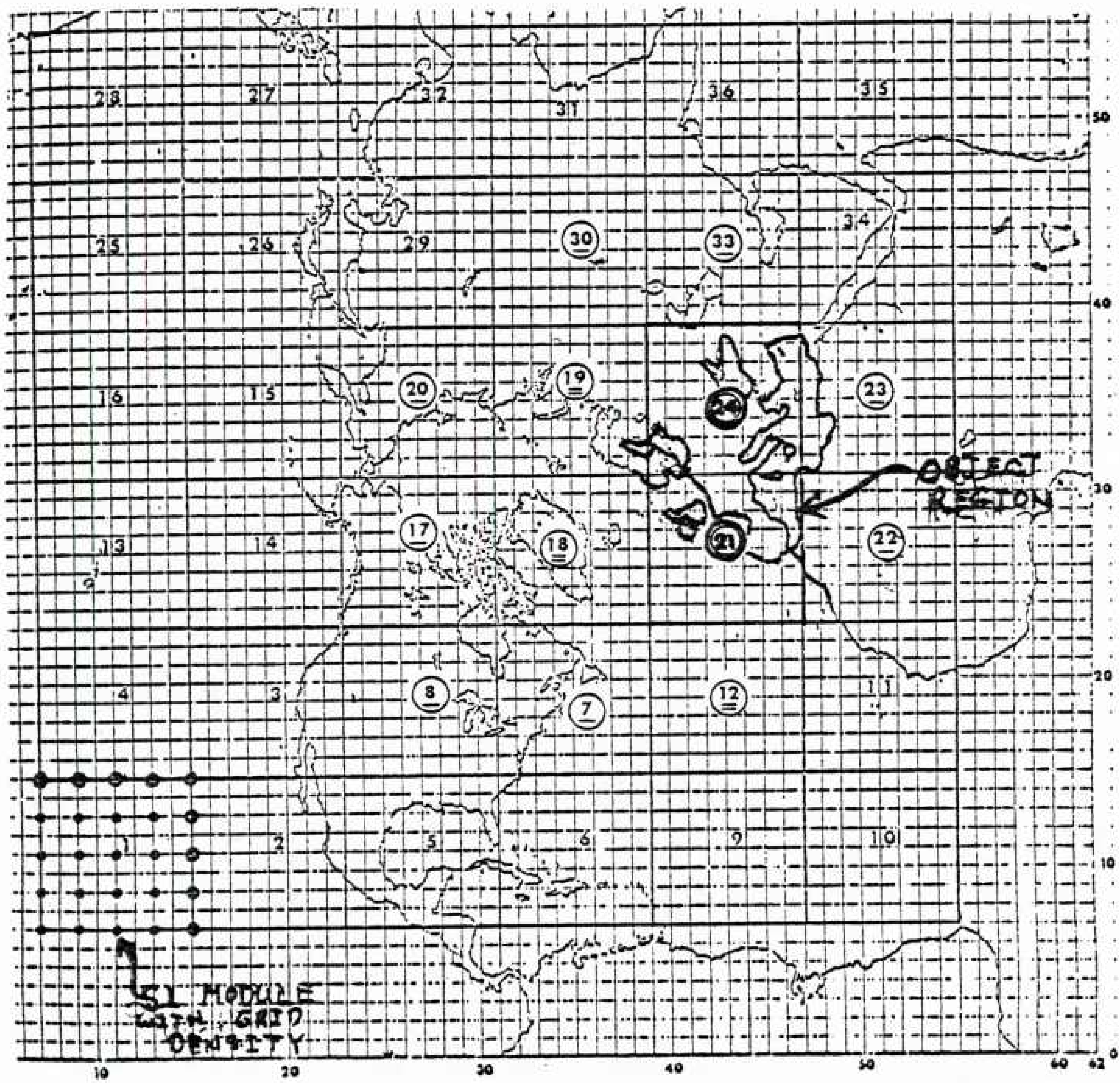


Figure 3. Greater Mediterranean focus for the SL component fields. (Resolution legend same as in Fig. 2.)

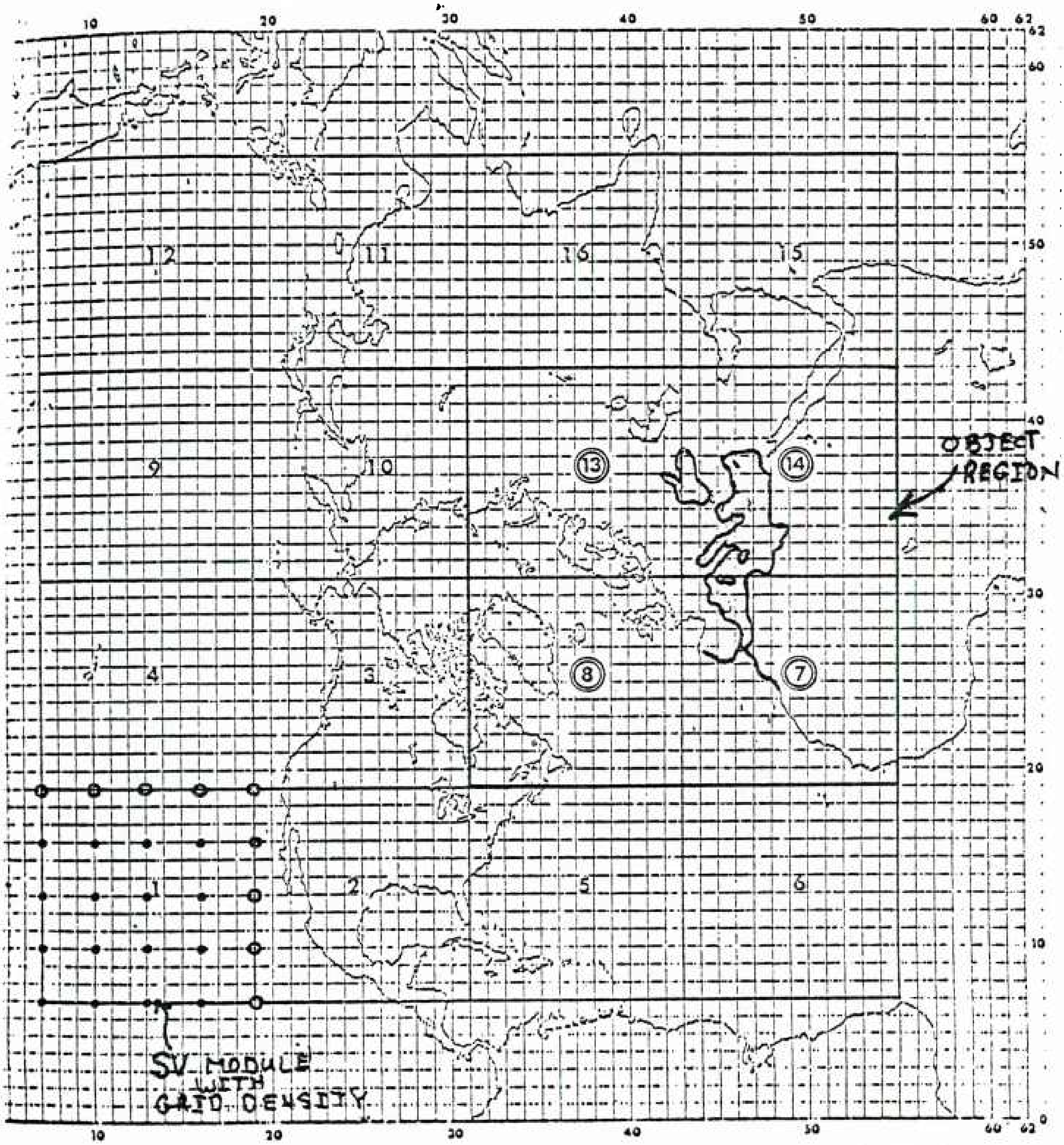
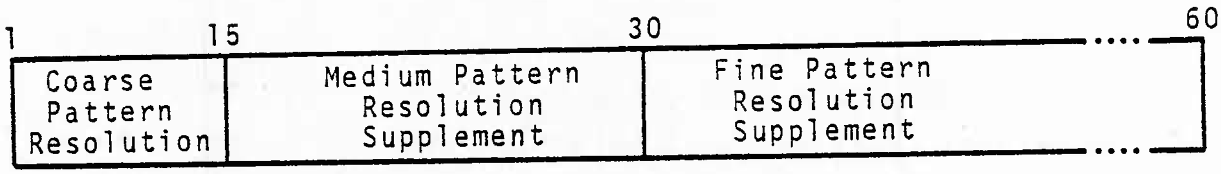


Figure 4. Greater Mediterranean focus for the SV component fields. (Resolution legend same as in Fig. 2.)



60 Bit CDC 6500 Word

Figure 5. Composition of 60-bit word for each IRRAS module.

3. BIT-CODING

For each module (4x4 array of grid points), the values of 17 different parameters are determined and bit-coded. Two of the parameters are actual height values at specific grid points within the module. The remaining 15 parameters are measures of gradients in several directions and over several length scales within the module.

The bit-code value of each paramter is assigned according to the deviation of this parameter from an assumed mean value of zero. This process is illustrated in Table 1 for the SL height parameter at 500 mb. As is shown in Table 1, the possible range of a parameter is divided into a number of bins, or "range intervals." These bins are grouped symmetrically about a central value of zero, with the zero value indicating the boundary between the two central bins. The boundaries between bins away from the central value have been determined statistically using the standard deviation of the measured parameter. This standard deviation is calculated using a combined summer and winter sample, including all modules for a particular level and pattern separation.

The number of bins is predetermined by the number of bits assigned to the parameter. The number of bins assigned varies from a maximum of 10 for the height parameters to a minimum of 4 for eight of the gradient parameters. For a given parameter, each bin is assigned a unique bit-code (last column in Table 1).

The comparison of a particular level and pattern separation for a historical date with the current date is easily accomplished by comparing the bins to which each parameter in each module is assigned, and giving the degree of match a score based on the number of bits (or bins) which represent the parameter.

IRRAS thus essentially measures the deviation of each parameter in each module from central value of zero and then compares the deviation of a historical field from that of the current field according to a predetermined standard deviation and weight (or number of bits) assigned to each parameter.

Table 1. Bit coding of SL height parameter A or B at 500 mb.

Value of Parameter (Meters)	Range Level	Assumed Frequency of Occurrence	Range Interval	Assigned Bit Code
		4.5%	1	0000000
124.07	1.700 $\bar{\sigma}$			
		8.0%	2	0000001
83.93	1.150 $\bar{\sigma}$			
		12.5%	3	0000011
49.26	0.675 $\bar{\sigma}$			
		12.5%	4	0000111
23.35	0.320 $\bar{\sigma}$			
		12.5%	5	0001111
0	0 $\bar{\sigma}$			
		12.5%	6	0011111
- 23.35	-0.320 $\bar{\sigma}$			
		12.5%	7	0111111
- 49.26	-0.675 $\bar{\sigma}$			
		12.5%	8	1111111
- 83.93	-1.150 $\bar{\sigma}$			
		8.0%	9	1111110
-124.07	-1.700 $\bar{\sigma}$			
		4.5%	10	1111100

Returning to Table 1, it is obvious from column 1 that the bins are not spaced equally. This should pose no problem for a parameter within a module which meets the assumed distribution (i.e., standard deviation) and assumed mean of zero. Unfortunately for the case of the SL scale, used as the primary scale for picking analogs (see later discussion in Section 5.2), possible seasonal and geographical variations in both the means and standard deviations of the various parameters will reduce the discriminatory power of IRRAS.

When the actual mean of a parameter within a given module is significantly shifted away from zero, the bit matching score for that parameter will be biased high. For example, assume that a particular module is located in the long-term, long-wave ridge so that by using Table 1, the mean value for the SL parameters, A and B, at 500 mb should be +80 m instead of zero. The result of this shift in the mean value is illustrated in Figure 6A, where the solid curve centered on zero represents the assumed distribution and the dashed curve centered at +80 m represents the actual

distribution. For this case it has been assumed that both curves have the same normal distributions. The range levels derived from the assumed distribution are shown along the abscissa of Figure 6A and are labeled from 1 to 10 (see Table 1 for the corresponding values of the parameters). It is apparent that the effect of shifting the actual mean away from the assumed mean is to reduce the number of bins into which the observed value of the parameter will generally be assigned. Thus the amount of discrimination between the historical case and the observed case is reduced.

Another situation warranting discussion is the likelihood that the standard deviation of a given parameter for a particular season and module will be significantly different from the standard deviation calculated over all modules and seasons. For example, assume that for a particular module during winter, the standard deviation of the SL parameters A and B at 500 mb is twice the value used in Table 1 (i.e., actual = 145.96 m). This case is illustrated in Figure 6B where, as in Figure 6A, the solid curve represents the assumed distribution from Table 1 and the dashed curve represents the actual distribution. Discrimination again is lost in this situation because a large number of cases end up in either bin 1 or bin 10, much more often than the assumed total frequency of occurrence of 9% shown in Table 1.

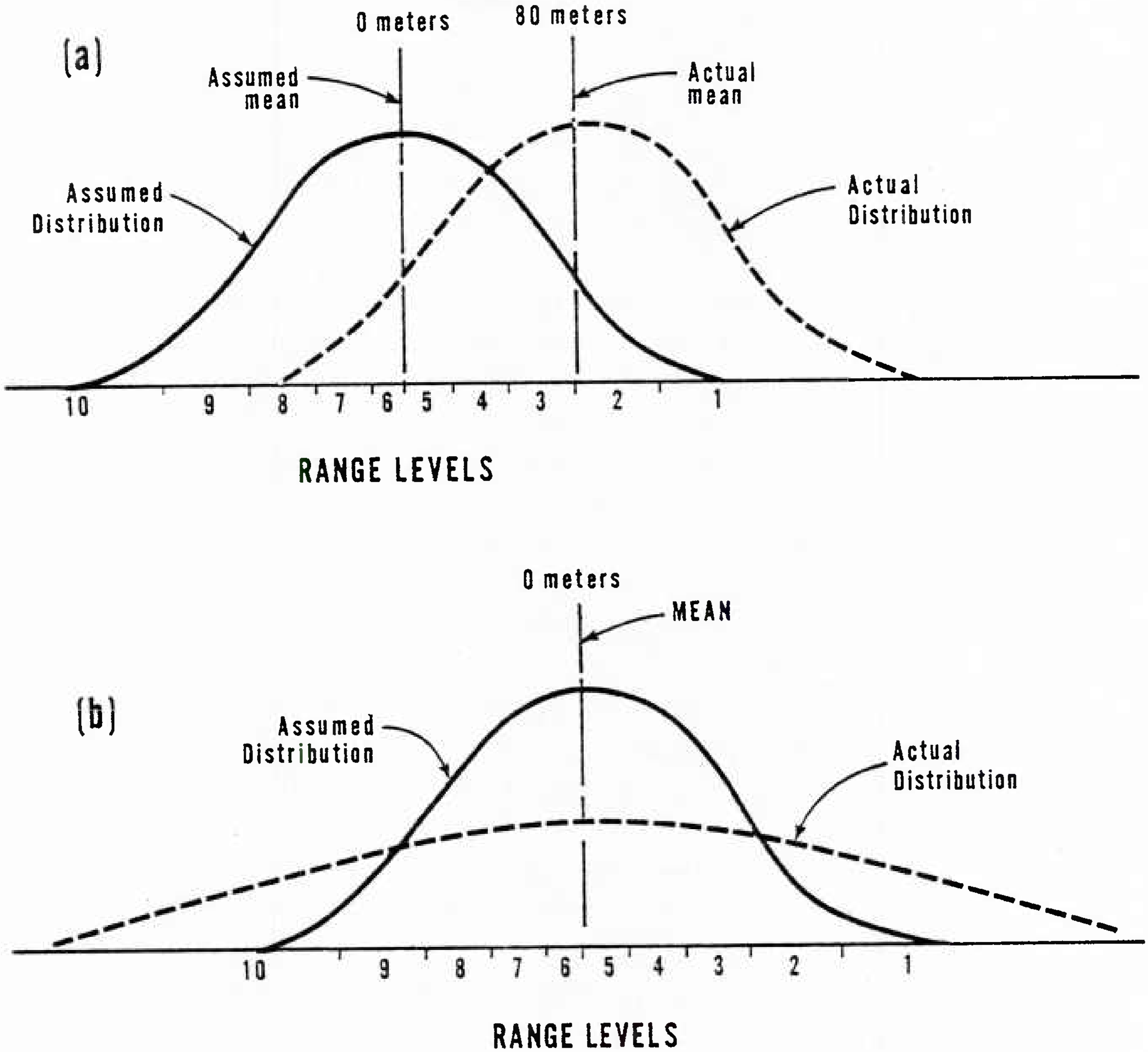


Figure 6. Schematic showing the effects of increasing the mean (a) and standard deviation (b) in reducing the discriminatory power of IRRAS.

4. REGIONAL FOCUSING

A useful property of IRRAS is the ease with which one can modify the bit-coded historical data base in order to regionalize the system. For a regional focus, such as the Greater Mediterranean region, it is only necessary to extract preselected modules, depending on the given pattern separation field, from the total bit-coded historical data base. For some of these modules, generally those farthest from the area of interest, only the coarse resolution data contained in the first quarter of each 60-bit word (see Figure 5) are saved. For other modules, the medium-resolution supplements in the second quarter of the 60-bit word are included. Finally, for modules in the vicinity of the area of interest, all information contained in the 60-bit word is saved.

Figures 2, 3 and 4 (refer to Section 2) show the regional focus used for the Greater Mediterranean region for the SD, SL and SV respectively. Using the SD regional focus (Figure 2) as an illustration, the individual modules in this example are made up of 16 grid points, i.e., the full density of the 63x63 grid array. Extractions of the bit-coded data are made only for the circled modules. A double circle indicates full resolution, a double bar in the circle indicates medium resolution, and a single bar in the circle indicates only coarse resolution for a particular module.

Note that the modules which included full resolution in Figures 2, 3, and 4 were picked to correspond as closely as possible to the Mediterranean Basin.

5. ANALOG SELECTION PROCESS

Theoretically, the procedure used to pick the best analogs for a current synoptic situation, baseday, is quite simple. The baseday is first bit-coded in the same manner as the historical data base. Next each analog candidate is scored by counting the number of matching bits between it and the bit-coded baseday. The analog candidates showing the highest count of matching bits are considered the best analogs. This procedure is described in more detail below.

5.1 TIME FUNNEL

A special technique incorporated into IRRAS is the capability of using a time-connected series of situations, a "scenario," in finding the best analogs. The advantage of scenario matching is illustrated using Figure 7. A meteorological situation, S, can be imagined as a point in N space where N is the number of specifying parameters. The evolution of S with time is indicated in Figure 7A, where S has been shown as a particular point at time t. In this example it is assumed that t is the baseday and S is the baseday situation to be used for the analog selection.

S is a point in N space only if the precise values of the specifying parameters are both known and used. In the case of IRRAS, however, the technique of using bins (range intervals) for bit-coding the specifying parameters, introduces uncertainty and S should be represented by a blob as shown in Figure 7B rather than a point.

Even allowing for the uncertainty in S, a precise match is most unlikely to be found. In general, analog candidates are scored and ranked, and the top-scoring analogs are selected. The minimum number of matching bits necessary for an analog candidate to be accepted describes a volume V, in N space about S, and is shown in Figure 7C.

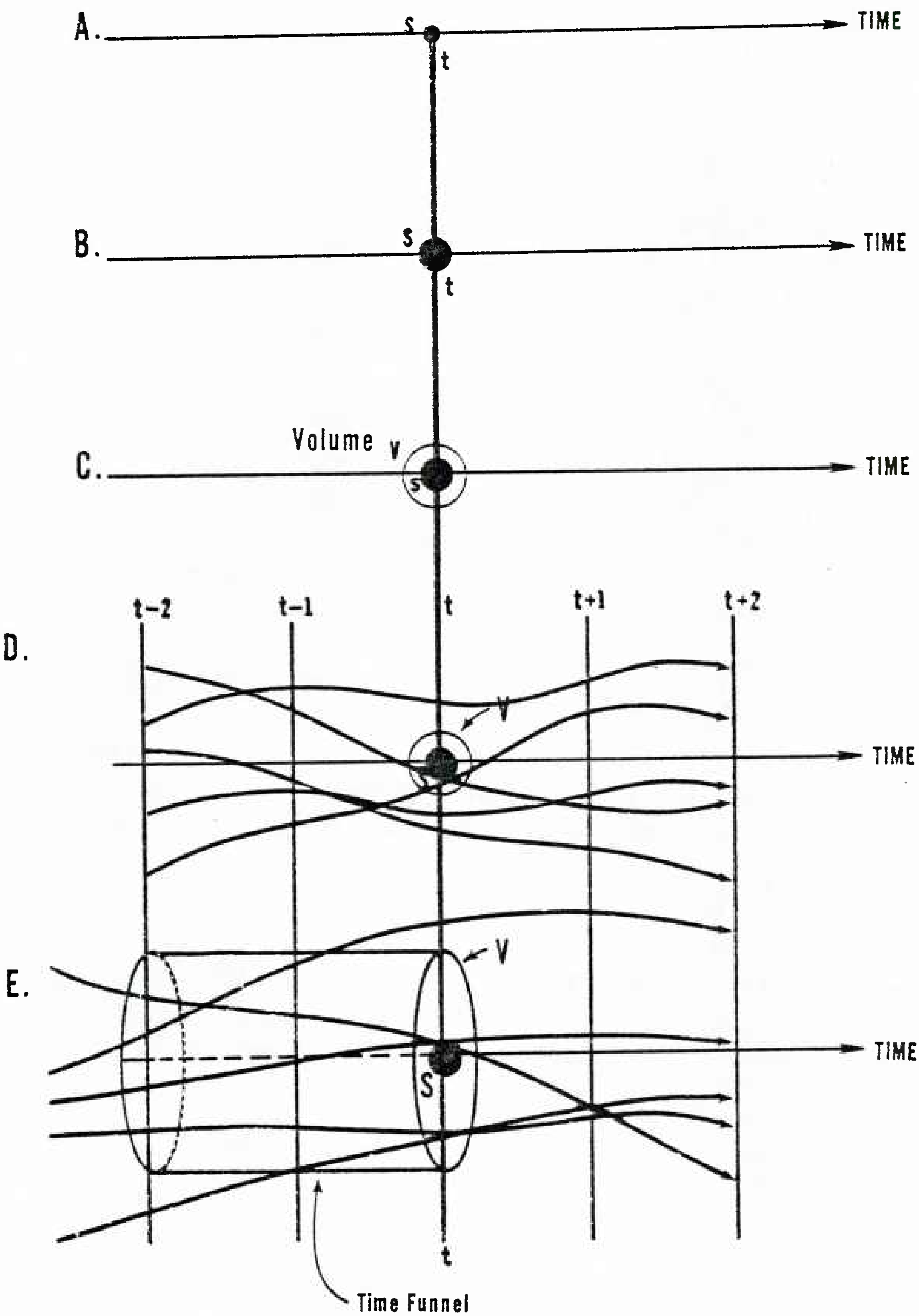


Figure 7. Schematic showing the advantages of using a time-connected series of situations, S, in finding the best analogs.

In the usual analog selection, a baseday is chosen and then the history is searched for meteorological situations whose evolution in time with respect to S as shown in Figure 7D pass through V. Candidates not passing through V (the vast majority) are rejected. The analog forecast valid at time t + 1 -- say 24 hours after baseday -- is a compilation of the analogs passing through V. The compilation is, of course, performed on the analog situations one time step, t + 1, -- 24 hours in this case -- later than when they passed through V.

One point is immediately apparent in an examination of Figures 7A through 7D: the best analog at time t is not necessarily the analog situation which will be closest to the evolution of the baseday situation S, at time t + 1. Thus an analog forecasting system based on the single best analog at time t is not likely to be consistently successful. At the very minimum, a compilation of a reasonable number of analogs is required (the FNOC operational analog averages 10 analog fields; see U.S. Naval Weather Service, 1975). It may also be noted, as is illustrated in Figure 7D, that the closest match(es) at time t + 1 may lie outside V at time t, and will therefore not be included in the compilation.

The procedures described above and illustrated in Figures 7A through 7D may be extended to illustrate scenario matching where, instead of an acceptable match at t only, an acceptable match over a period of time is required. To be successful, analog candidates must enter and pass through a "time funnel" (Figure 7E) requiring that the match maintain in this case over two time intervals, from t-2 to t. Note that a cylindrical time funnel, as seen in Figure 7E, requires that the number of matching bits remains within V for the whole time period, t-2 to t.

The time-funnel concept can also be used to incorporate the skill inherent in numerical forecast models. Consider again the meteorological situation S at time t as being the current situation. Scenario matching from, say, t - 72 hours to t can be carried out as previously described. Using the current FNOC operational forecast model, forecast situations can be incorporated

to extend the time funnel into the future, say, to t + 72 hr as shown in Figure 8. Again only analog candidates which remain within V for the whole range of t (in this case from t - 72 hr to t + 72 hr) are used to compile analog forecasts which would start beyond the end of the time funnel -- later than t + 72 hr.

Note that as is shown in Figure 8, the time funnel used in IRRAS need not be symmetrical. The volume V, for example, which matching bits must remain within, can vary with time. Also, the time periods about the baseday need not be the same.

5.2 SELECTION AND TUNING PROCEDURES

There are essentially two sets of tuning controls used in the IRRAS analog selection process: the selection gates, and weighting factors. The selection gates control the number of analogs selected by varying the volume V; the weights decide the final rankings of analogs by adjusting the relative significance of any chosen pattern characteristics.

The selection gates are important in IRRAS because if too many analogs are scored, selected, and ranked, computer resources will be utilized unnecessarily. On the other hand, if too few analogs are selected, the process has to be repeated after increasing volume V, which again wastes computer resources. In the IRRAS selection process, the primary use of the selection gates has been to remove analog candidates which come from an entirely different season than the baseday (i.e., summer vs. winter). The selection gates, however, will occasionally allow cases such as early spring and late autumn to be grouped together. The SV fields have shown their greatest value in the selection gate process due to the complete reversal of north-south gradients in these fields between summer and winter.

The weighting factors are important in the final selection process, since varying these factors allows the relative significance of any input component to be controlled. There are 9 of these components for each level in the bit-coded data base -- 3 ranges-of-scale times 3 degrees-of-resolution. For example, SD is the smallest range-of-scale and the first quarter of the 60-bit word gives the coarse resolution.

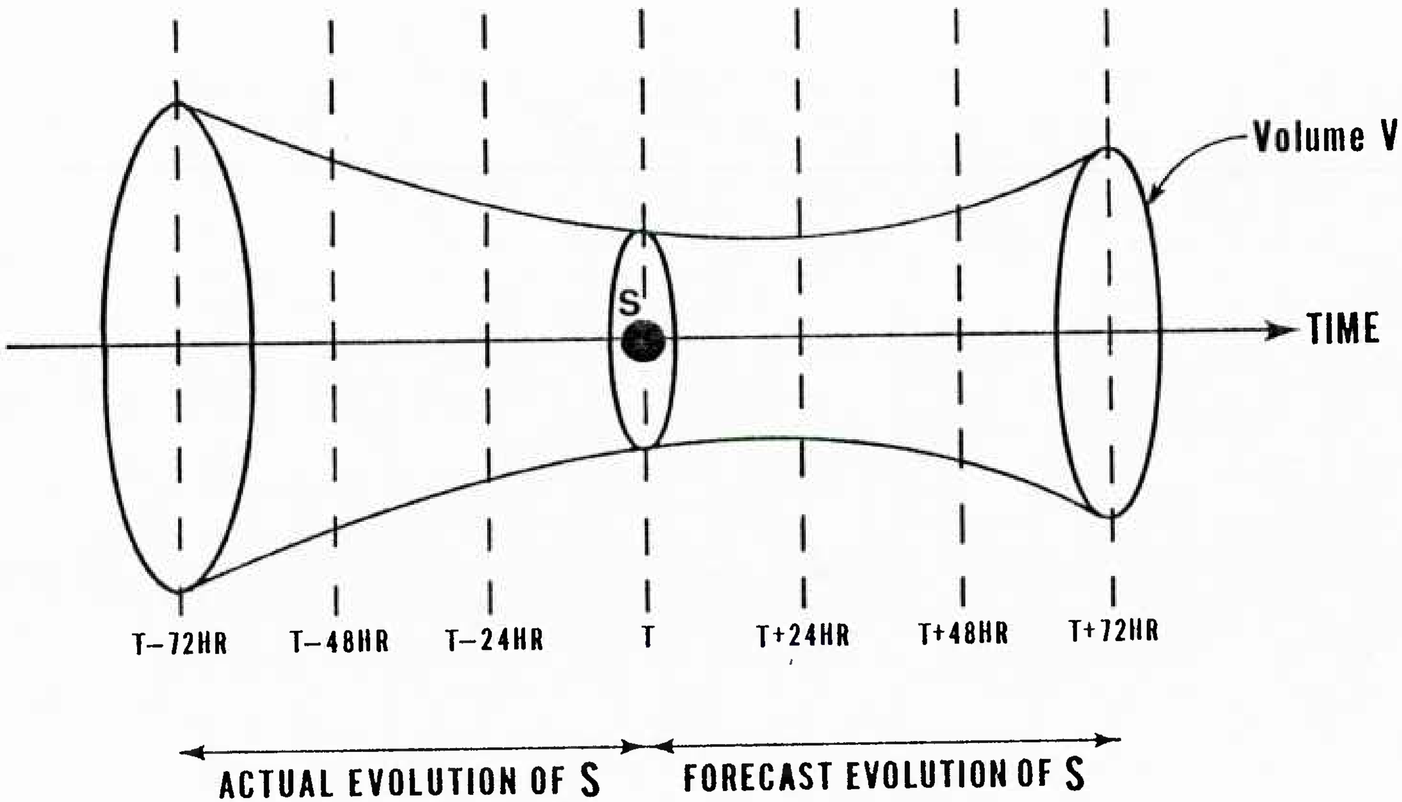


Figure 8. Schematic of time funnel incorporating both analyses and forecasts of the meteorological situation S.

Unfortunately, the use of the weighting factors are also needed to cope with a serious problem inherent in the IRRAS data base. Although the three ranges-of-scale are probably adequate to represent the various scales of atmospheric disturbances in space, there is a range-in-time that must also be considered. The SV fields vary slowly, the SL fields vary more quickly, and the SD fields vary rapidly. The IRRAS data base contains a complete record only every 24 hours. The SD fields would be needed at least every 6 hours. Thus the data base is completely inadequate for this scale, requiring weighting factors to be made very small for the SD range-of-scale.

The weighting factors used in the tuning process of IRRAS are shown in Figure 9. In this schematic, the relative importance of the various components and various times used in the time funnel are indicated by the height of the various blocks. The length of the time funnel is from t - 72 hr to t + 72 hr for both the SV and SL scales, but only from t - 24 hr to t + 24 hr for the SD scale. The relatively very low weights and short time funnel assigned to the SD scale were the results not only of the problems described earlier in this section, but also of the lack of skill inherent in the current FNOC operational forecast model in the SD scale.

As is indicated in Figure 9, the weights assigned the SL scale are in every case larger than the SV scale. The SL scale has much more discriminating power between various synoptic weather situations, while the SV scale appears to have value as a seasonal discriminator. The weighting factors for the SL scale were made larger along the positive time axis, compared to the negative time axis, in order to incorporate as much of the skill in the FNOC operational forecast model as possible.

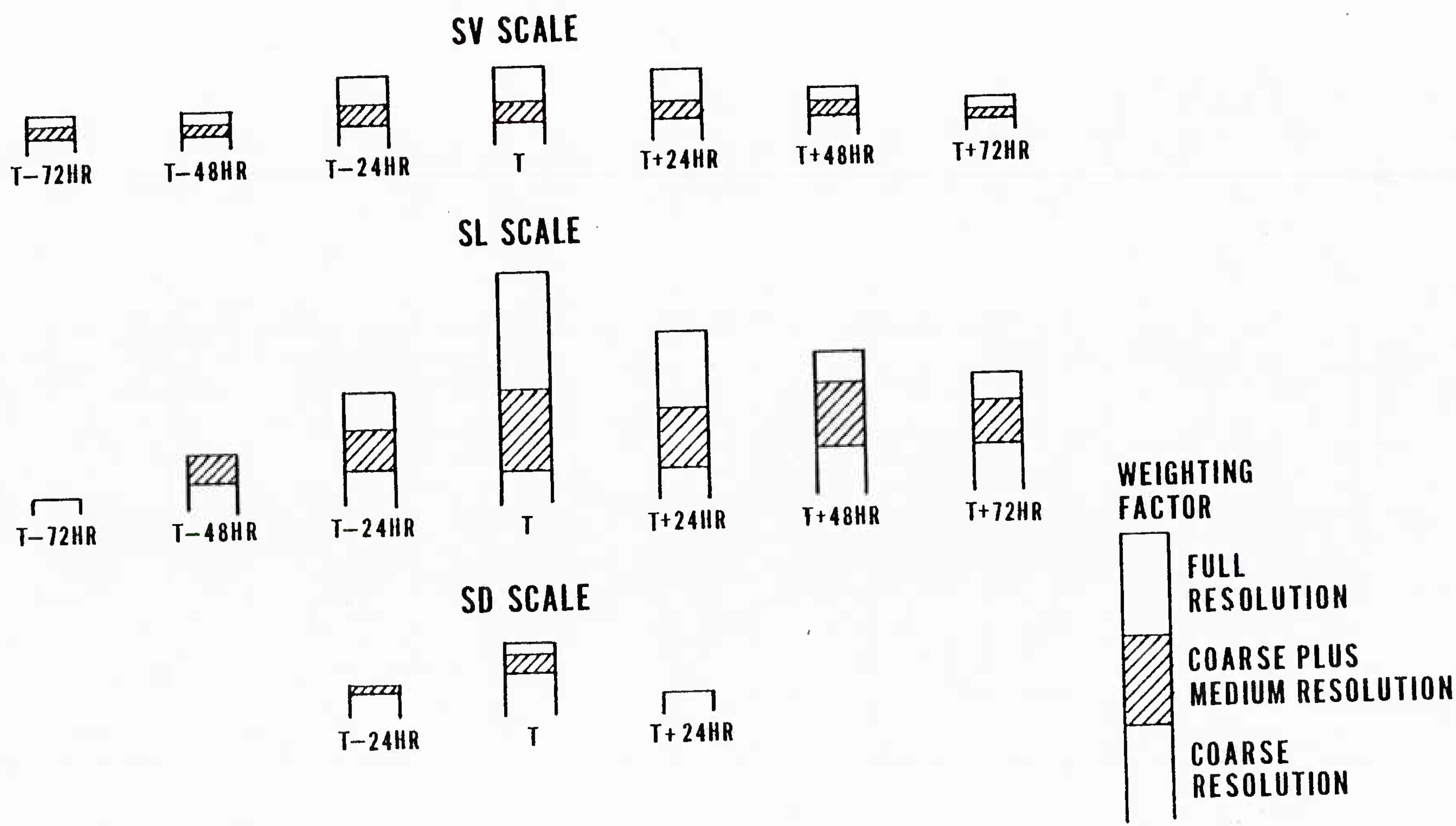


Figure 9. Schematic showing time funnel centered at time T with relative size of weighting factors used in the IRRAS tuning process.

6. VERIFICATION SYSTEM

The IRRAS verification system is designed to operate on a smaller area than that used in the analog selection procedures. This area, called the object region, is defined as those modules, appropriate to each range-of-scale, for which full bit-code resolution is used during the analog selection (see Figures 2, 3 and 4 for these regions). In actuality, only the SL scale was verified. As described in Section 5, there were problems in using the SD scale in the selection process, so this scale was not verified. The SV scale was not verified due to the lack of daily synoptic information inherent in this scale.

The object region used as verification for the Greater Mediterranean region is shown in Figure 10. The full-resolution modules making up the object region did not extend into North Africa, a reasonable exclusion because of the relatively poor analyses found over that area in the analog history data base, especially at the 500 mb level.

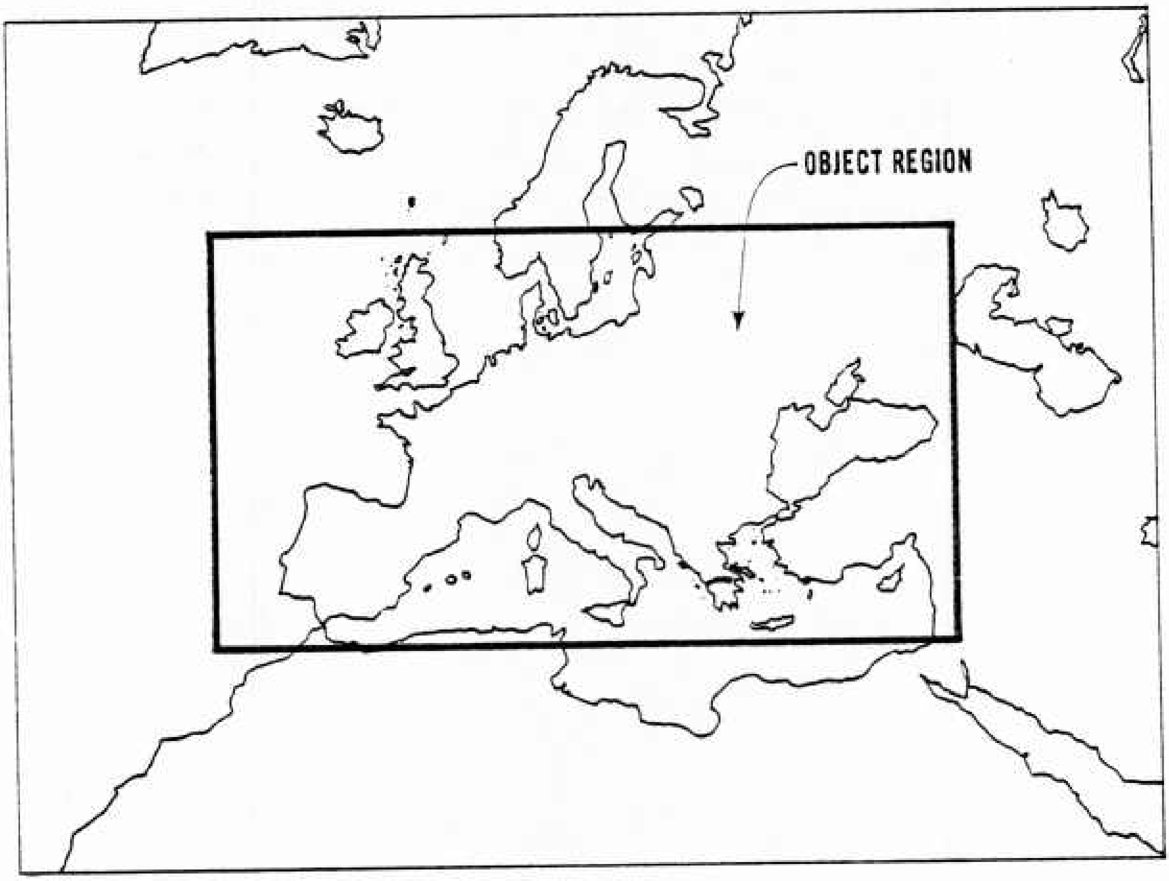


Figure 10. Object region for the SL scale used in the verification of IRRAS for the Greater Mediterranean region.

In the verification procedures the top N analogs (where N can be specified) are matched against the day-to-day evolution of the baseday situation out to eight days over the object region shown in Figure 10. The bit-coding techniques described in Section 3 are used. A persistence verification is also carried out for comparison purposes; for a selected baseday, the ensuing events at 24 hour intervals out to eight days are bit-matched against the baseday.

7. IRRAS VERIFICATION

The verification study, made to test the reliability of IRRAS as a forecast tool, was performed in two phases. The first phase, associated with tuning the system, was carried out using a selection of cases of particular interest to the Mediterranean forecaster. The second phase used the then-tuned IRRAS in direct competition with the FNOC operational analog.

7.1 TUNING STUDY

The 33 basedays picked from the history data base and used to tune IRRAS for the Greater Mediterranean region are listed in Table 2. These basedays were chosen to include the most important of the large-scale weather patterns of the Mediterranean as described in Air Ministry (1962). Included were both cases which remained within one Air Ministry weather type throughout the entire eight day forecast period, relatively persistent in the SL scale; and cases which changed from one Air Ministry weather type to another, not persistent in the SL scale. The cases were chosen from the more recent years of the history data bases, December 1970 through April 1975, in order to ensure the best quality analyses available. All the cases also were picked from the middle of November through the middle of April so as to emphasize seasons when major changes are most likely to occur and are thus most difficult to forecast.

Several parameters described in earlier sections can be varied to tune IRRAS, which would have an effect on the analog dates chosen from the historical data base. These parameters are regional focus specification, time funnel, selection gates, and weighting factors.

The regional focus for the Greater Mediterranean region was set at the beginning of the tuning process and never changed; this focus for the three ranges-of-scale is shown in Figures 2, 3 and 4 in Section 2. The regional focus was designed both to allow upstream influences to affect the object region and to exclude as much as possible those modules which included very little real data (e.g., North Africa).

Table 2. Dates of 33 basedays (times are 12Z) used in tuning study of IRRAS for the Greater Mediterranean region.

1970	1971	1972	1973	1975
6 Dec	18 Jan	10 Jan	18 Jan	6 Jan
20 Dec	26 Jan	27 Jan	30 Jan	23 Feb
	5 Feb	9 Feb	22 Feb	27 Feb
	14 Feb	24 Mar	6 Mar	21 Mar
	22 Feb	8 Apr	11 Dec	1 Apr
	1 Mar	15 Nov	23 Dec	10 Apr
	6 Mar	22 Nov		
	12 Mar			
	12 Nov			
	18 Nov			
	21 Nov			
	22 Nov			

The time funnel went through a considerable evolution during the tuning process. Initially, for example, it was allowed to extend only from t - 24 to t + 24 hr in the SL scale. Later, it was generalized; the final time funnel used in the tuning process is shown in Figure 9. This final time funnel ran from t - 72 hr to t + 72 hr for both the SV and SL scales, and from t - 24 hr to t + 24 hr for the SD scale.

The selection gates described in Section 5.2 are used primarily to remove unwanted dates (i.e., summer vs. winter) from the list of possible analogs. If too few cases (fewer than 80) pass through the selection gates, IRRAS is designed to lower the gates to allow more cases to pass through. The selection gates represented as the number of bits allowed to mismatch are listed in Table 3.

The weighting factors appeared to have the greatest effect on the tuning process and were also the most difficult to handle in a systematic way. For example, the weighting factors could be different for each of the 3 ranges-of-scale and 3 degrees of resolution for each time period making up the time funnel. With 7 time periods (i.e., every 24 hours from t - 72 hr through t + 72 hr) there are a total of 3x3x7 = 63 weighting factors for each level (i.e., 500 mb, 1000 mb and 1000-500 mb thickness). Thus there are a possible 189 weighting factors which can modify

Table 3. Selection gates, given as the maximum number of mismatching bits allowed for a potential analog to be selected for the Greater Mediterranean region.

Time (hr)	Resolution	GATES								
		SV			SL			SD		
		500 mb	1000 mb	500-1000 mb	500 mb	1000 mb	500-1000 mb	500 mb	1000 mb	500-1000 mb
0	C M F	20 20 20	20 20 20	20 20 20	35 35 35	35 35 35	35 35 35	45 45 45	45 45 45	45 45 45
-24	C M F	25 25 25	25 25 25	25 25 25	40 40 40	40 40 40	40 40 40	45 45	45 45	45 45
+24	C M F	25 25 25	25 25 25	25 25 25	40 40 40	40 40 40	40 40 40	50	50	50
-48	C M F	30 30 30	30 30 30	30 30 30	40 40	40 40	40 40			
+48	C M F	30 30 30	30 30 30	30 30 30	40 40 40	40 40 40	40 40 40			
-72	C M F	35 35 35	35 35 35	35 35 35	45	45	45			
+72	C M F	35 35 35	35 35 35	35 35 35	45 45 45	45 45 45	45 45 45			

the final selection score. A list of the weighting factors used in the tuned IRRAS are found in Table 4 (refer also to Figure 9 in Section 5.2).

As can be seen from both Table 4 and Figure 9, the weighting factors were tuned to emphasize the SL scale and the forecast part of the time funnel. This emphasis allowed the selected analogs to agree more closely with the numerical forecasts in the range-of-scale to be verified, the SL scale.

The results of the tuning phase of IRRAS for the Greater Mediterranean region are shown in Figures 11, 12 and 13 for the SL scale at the 500 mb and 1000 mb levels, and for the 500-1000 mb

Table 4. Weighting factors used by IRRAS for the Greater Mediterranean region.

Time (hr)	Resolution	SV 500 mb	SV 1000 mb	SV 500-1000 mb	SL 500 mb	SL 1000 mb	SL 500-1000 mb	SD 500 mb	SD 1000 mb	SD 500-1000 mb
0	C	0.50	0.25	0.50	1.00	1.00	1.00	1.00	1.00	1.00
	M	0.50	0.25	0.50	2.00	2.00	2.00	0.50	0.50	0.50
	F	1.00	0.50	1.00	3.00	2.00	2.00	0.25	0.25	0.25
-24	C	0.50	0.25	0.50	1.00	1.00	1.00	0.50	0.50	0.50
	M	0.50	0.25	0.50	1.00	1.00	1.00	0.25	0.25	0.25
	F	0.75	0.50	0.75	1.00	1.00	1.00			
+24	C	0.50	0.25	0.50	1.00	1.00	1.00	0.50	0.50	0.50
	M	0.50	0.25	0.50	1.50	1.00	1.00			
	F	0.75	0.50	0.75	2.00	1.50	1.50			
-48	C	0.25	0.10	0.25	0.75	0.50	0.50			
	M	0.25	0.10	0.25	0.50	0.25	0.25			
	F	0.25	0.10	0.25						
+48	C	0.50	0.25	0.50	1.50	1.00	1.00			
	M	0.50	0.25	0.50	1.50	1.00	1.00			
	F	0.25	0.25	0.25	1.00	0.75	0.75			
-72	C	0.25	0.1	0.25	0.25	0.25	0.25			
	M	0.25	0.10	0.25						
	F	0.25	0.10	0.25						
+72	C	0.50	0.25	0.50	1.50	1.00	1.00			
	M	0.25	0.10	0.25	1.00	0.75	0.75			
	F	0.25	0.10	0.25	0.75	0.50	0.50			

thickness, respectively. The scores shown on the diagrams are normalized so that a perfect score is 1000; scores were calculated only for the object region shown in Figures 3 and 10.

In Figures 11, 12 and 13, the new time-funnel curve was made up from the average of the best candidates for each of the 33 test cases using the weighting factors shown in Table 4. The old time-funnel curve used weighting factors for a time funnel extending only from t - 24 hr to t + 24 hr. The persistence curve, calculated as described in Section 6, was used only for comparison purposes.

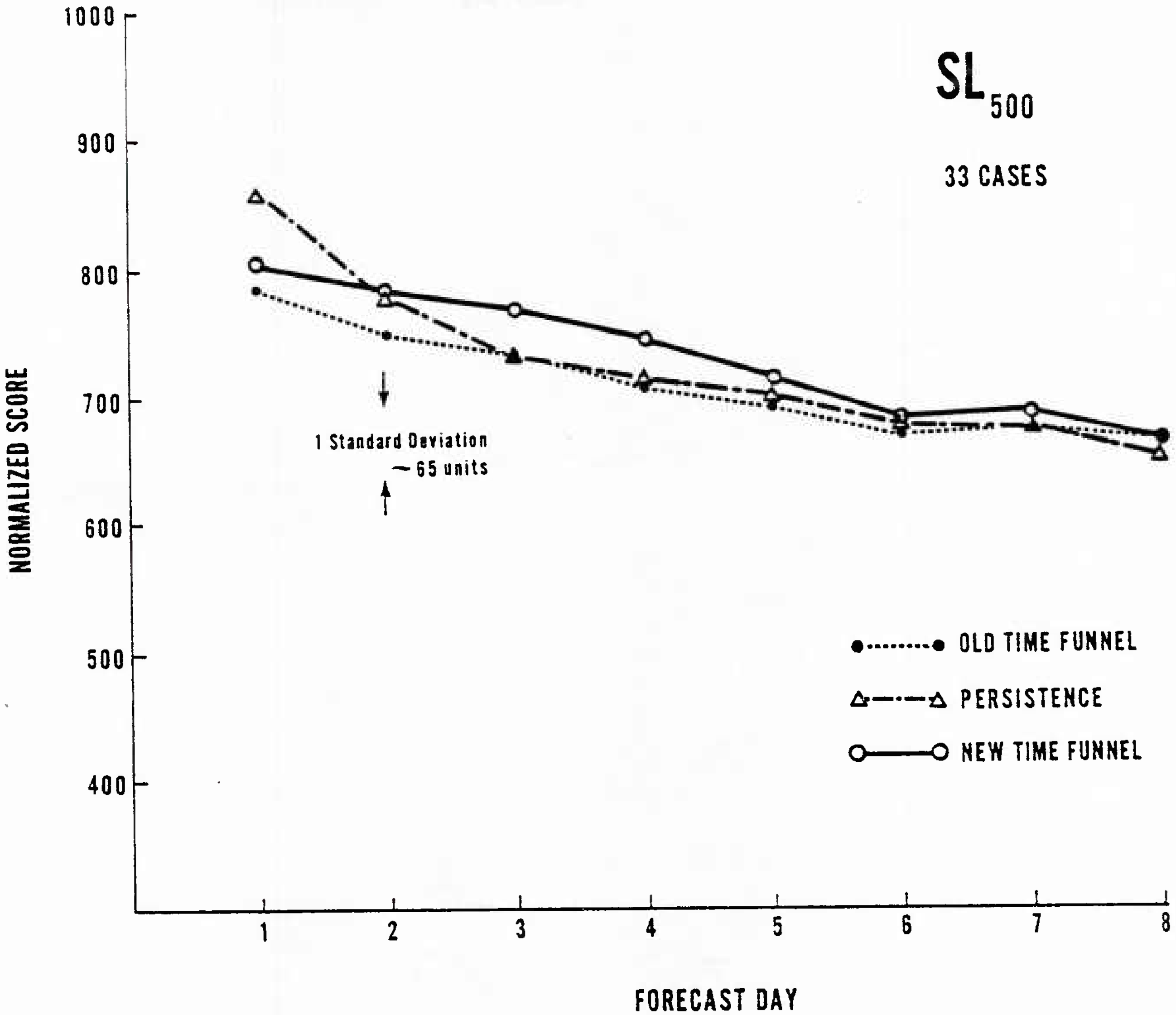


Figure 11. Results of tuning phase of IRRAS for the Greater Mediterranean region for the SL scale at the 500 mb level.

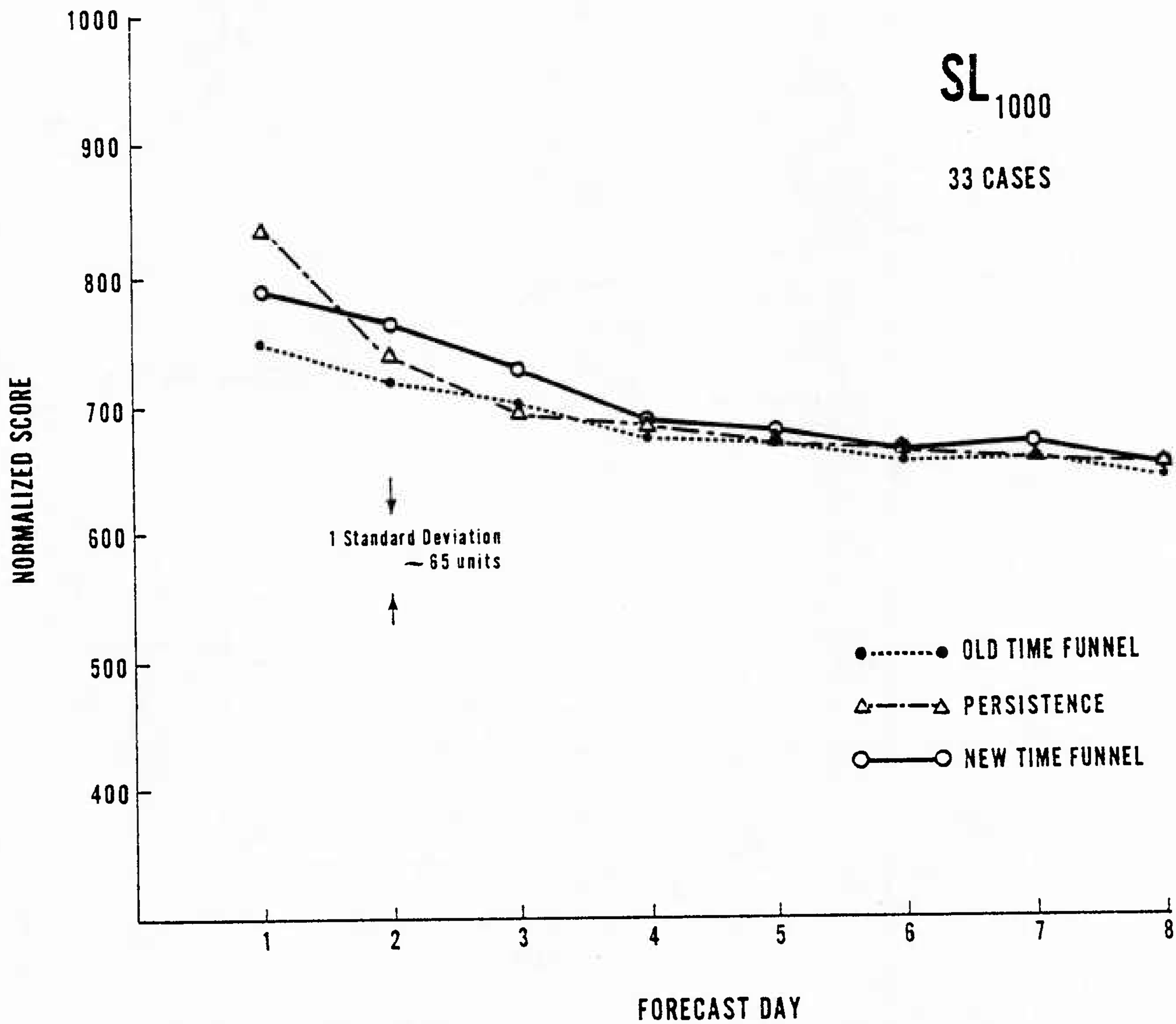


Figure 12. Same as Fig. 11, but at 1000 mb.

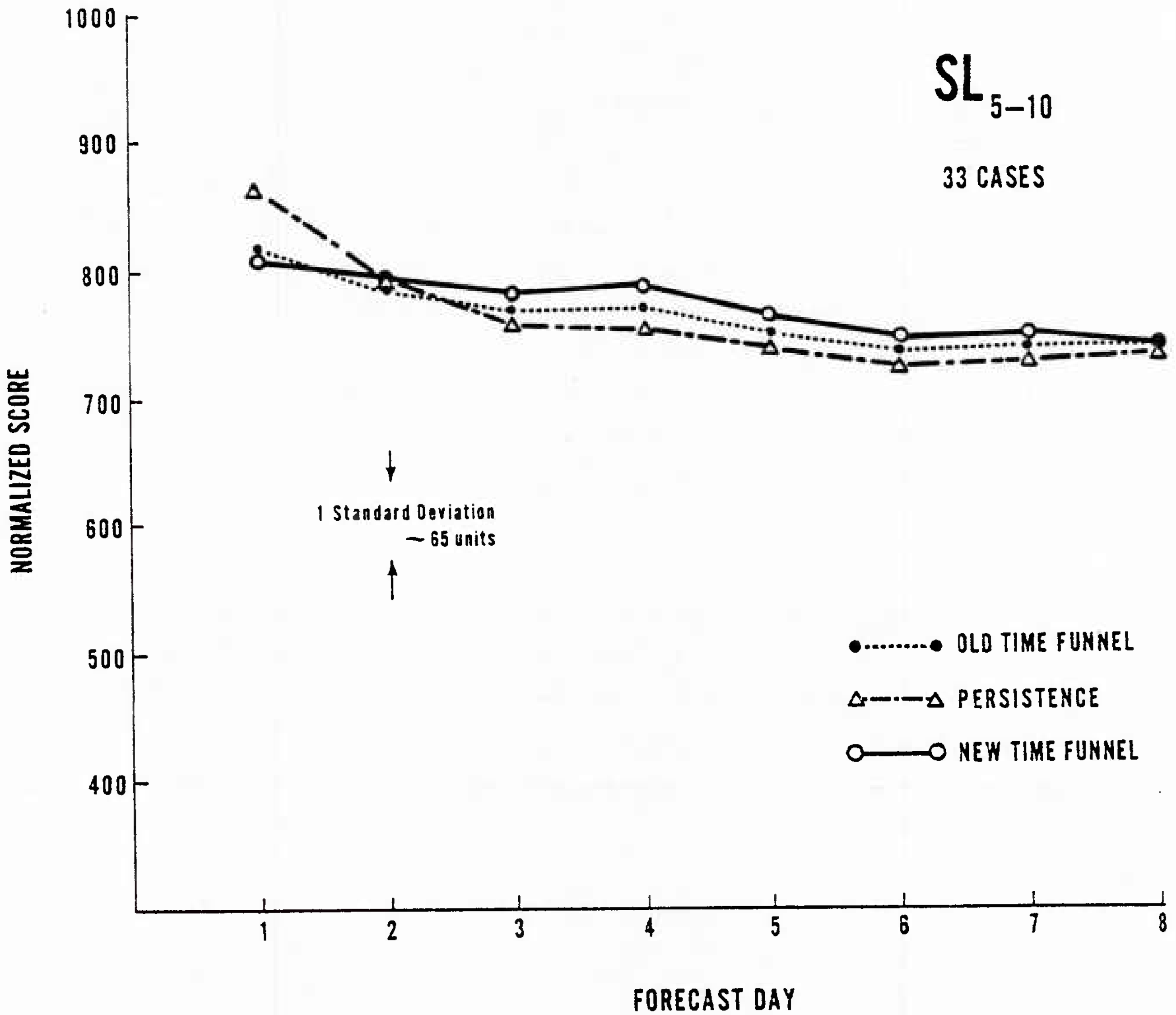


Figure 13. Same as Fig. 11, but for 500-1000 mb thickness.

Figures 11, 12 and 13 indicate that the results of the tuning phase of IRRAS are quite disappointing. In all cases, the three sets of curves are very close together (especially after the third day, t + 72 hr), well within one standard deviation (approximately 65 units) of each other. In all cases, persistence appears better than either of the other two curves at day one (t + 24 hr). The new time funnel appears better from the second to fourth day, but it must be remembered that this time funnel extended out to the third day. Only for the 500-1000 mb thickness does the new time funnel appear better than persistence beyond the fourth day of the forecast period.

7.2 COMPARISON STUDY

In order to compare IRRAS with the FNOC operational analogs, IRRAS was run for a series of basedays from December 1974 through February 1975 for which results of the operational analog were available. The dates used are listed in Table 5. The region forecasted by the FNOC operational analog, called the eastern Atlantic-Mediterranean sector (ELANT/MED), covers a sector from 60°E to 40°W.

Since the FNOC operational analog uses a composite of the 10 best candidates, the top 10 candidates from each analog model for the cases listed in Table 5 were included in the comparison. Also, since the FNOC operational analog does not use forecast data as input, IRRAS was run in two different modes for comparison. The first mode used only current and past data (i.e., only one half of the time funnel), while the second mode used forecast data out to 72 hours (i.e., full time funnel).

Figures 14 and 15 show the comparison between the FNOC operational analog, ELANT/MED sector, and IRRAS using both the full time funnel and one-half time funnel. As in Figures 11, 12 and 13, the scores are for the object region shown in Figures 3 and 10, and are normalized so that a perfect score is 1000. Persistence, as described in Section 6, is included again for comparison purposes. To aid in interpreting the scores, results of a verification study of the FNOC NHPE model during the 1980 winter season out to 72 hrs (3 days) also are included as a reference.

Table 5. FNOC operational analog picks
for the ELANT/MED (60E-40W) area.

Baseday	Best Dates	Baseday	Best Dates
YR MN DY HR	YR MN DY HR	YR MN DY HR	YR MN DY HR
74 12 15 12	49 12 03 12	75 01 26 12	57 01 05 12
	66 12 25 12		57 01 06 12
	66 12 24 12		57 01 28 12
	66 12 30 12		57 02 01 12
	66 12 31 12		67 02 21 12
	57 12 25 12		57 01 08 12
	64 12 10 12		57 01 31 12
	64 12 09 12		62 01 11 12
	66 12 18 12		57 01 09 12
	66 12 26 12		57 01 07 12
74 12 29 12	51 11 30 12	75 02 09 12	73 01 10 12
	51 12 04 12		53 01 24 12
	51 11 29 12		53 01 23 12
	47 12 26 12		66 02 04 12
	51 01 18 12		66 02 03 12
	51 12 01 12		50 03 08 12
	49 01 14 12		67 01 27 12
	51 12 03 12		67 01 28 12
	51 12 02 12		50 03 09 12
	53 11 30 12		55 01 29 12
75 01 12 12	46 01 00 12	75 02 23 12	49 01 28 12
	46 01 09 12		49 01 27 12
	46 01 08 12		59 01 27 12
	46 01 10 12		63 02 28 12
	48 01 06 12		72 03 15 12
	72 12 13 12		59 03 21 12
	46 01 07 12		59 03 20 12
	49 02 09 12		61 02 18 12
	48 01 13 12		63 03 01 12
	62 01 12 12		59 01 26 12

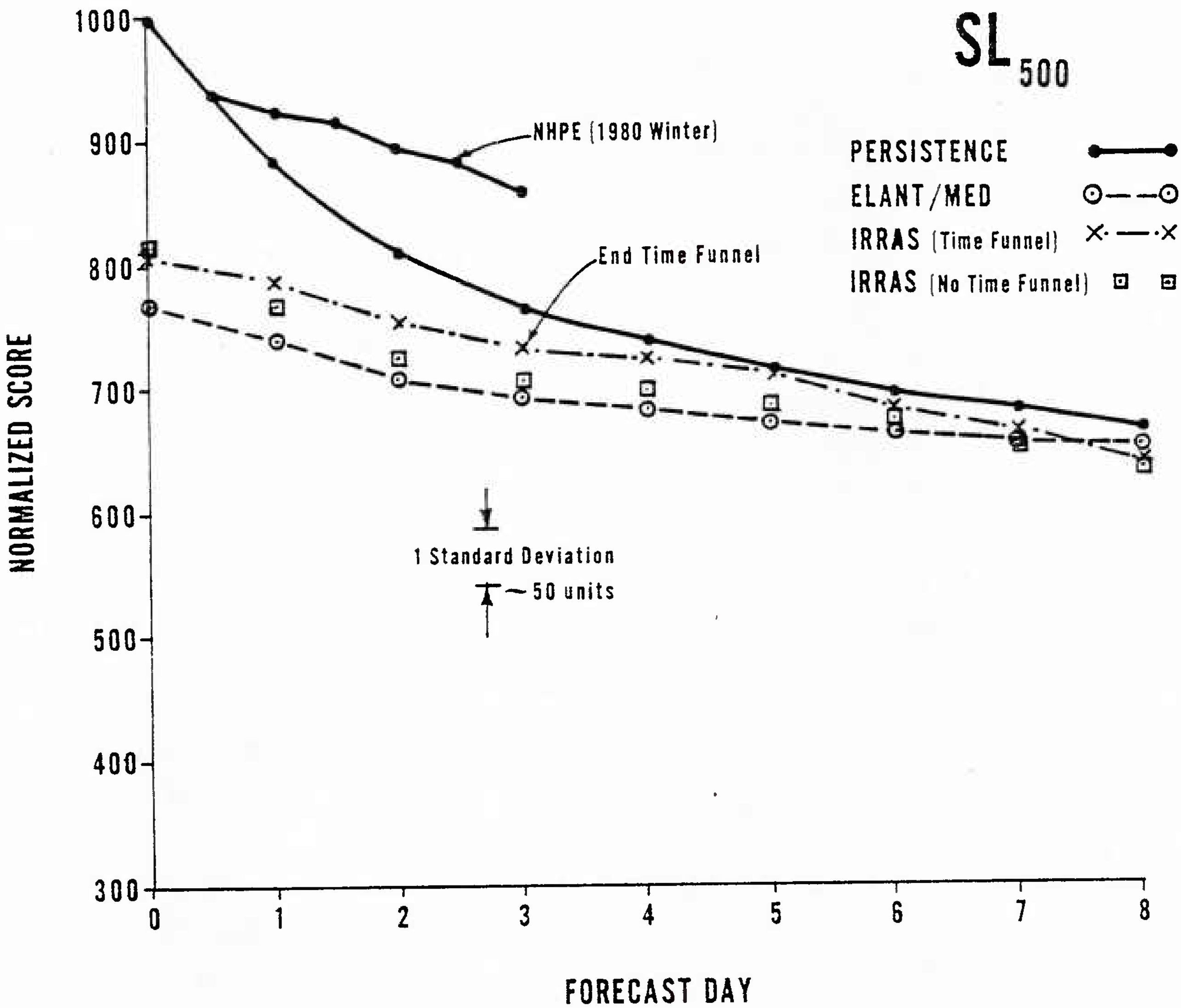


Figure 14. Results of comparison study for the SL scale at 500 mb, comparing IRRAS for the Greater Mediterranean region with the FNOC operational analog ELANT/MED sector.

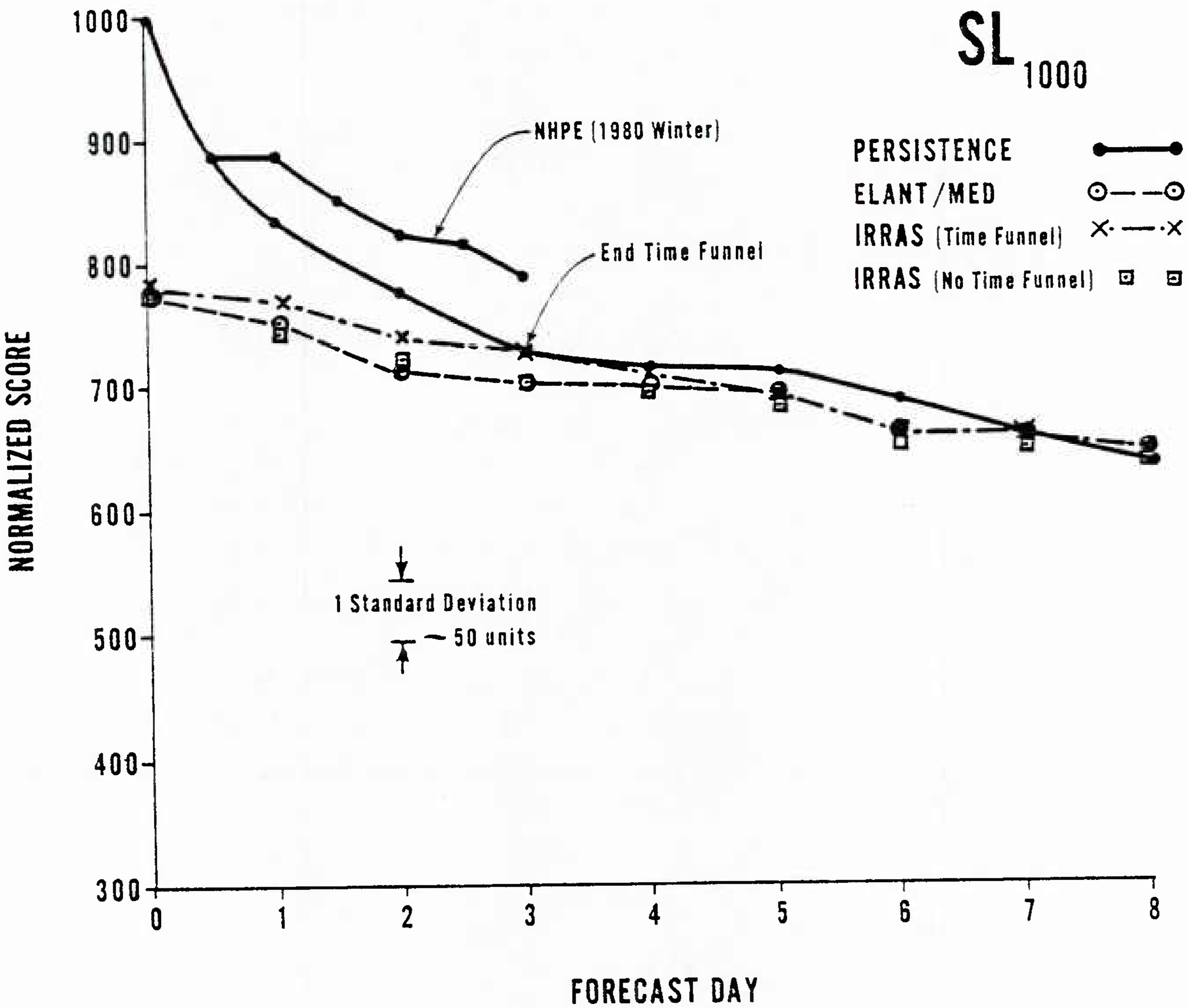


Figure 15. Same as Fig. 14, but for the SL scale at 1000 mb.

At 500 mb (Figure 14), it is apparent that neither of the analog systems beats persistence. Only the IRRAS mode using full time funnel appears to score as high as persistence during forecast days 4 and 5 (no comparison should be made during the first 3 days due to the use of the full time funnel).

At 1000 mb (Figure 15), again neither of the analog systems beats persistence. In this case, however, the IRRAS mode using full time funnel shows results similar to those of ELANT/MED and the other IRRAS mode beyond 3 days.

Another good indicator of the fact that neither of the analog systems produce much useful information can be obtained by looking at the scores produced by the FNOC NHPE model shown in Figures 14 and 15. As expected, the FNOC NHPE model beats persistence out to 3 days in the SL scale at both 500 mb and 1000 mb. Since this model is approaching the limits of its usefulness by the end of this time, a good measure of an acceptable normalized score is about 850 units at 500 mb and 800 units at 1000 mb. These values are much higher (greater than 2 standard deviations) than the scores obtained by either analog system.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 CONCLUSIONS

The results of the tuning and verification studies described in the preceding section show little skill in the IRRAS analog forecasts for the Greater Mediterranean region. Among the possible causes of those results are:

- An insufficient length of the data base to search for analogs.
- An inadequate range-in-time for the rapidly varying SD scale.
- Incorrect assumptions concerning the assumed means and standard deviations used in the bit-coding procedures.
- A lack of sufficient levels and/or other pertinent information necessary to define atmospheric situations and thus reliable analog cases.
- The general nonlinearity of the atmosphere -- not included in an analog system.

It would appear at first glance that the IRRAS historical data base of 30 years would be sufficient to find good analogs for a current baseday situation, at least in the SL scale. However, it was observed that when a baseday was selected from the historical data base, at least 8 out of the 10 best analog candidates were clustered around that baseday. This clustering indicates that persistence, in some cases out to several days, beat any of the other analog cases and thus points out the lack of good analog matches in the remainder of the data base.

The problems concerning the range-in-time of the SD scale are discussed in detail in Section 5.2. Because of these problems, the weighting factors for this scale were made extremely small. Thus a large portion of the history data base was excluded from the analog matching. This lack of a useful analog data base for the SD scale presented an even more serious problem in the study to determine the usefulness of the IRRAS data base in finding analogs for Silent Data Areas (discussed in Appendix A).

As described in Section 3, the assumptions used for the bit-coding procedures were probably incorrect. It is likely that seasonal and geographical variations in both the means and standard deviations, as used in the bit-coding procedures, decrease the discriminatory power of IRRAS for comparing historical analogs with the observed baseday.

Although IRRAS incorporates information about low and mid-level flow along with the thermal structure (thickness) of the atmosphere, upper level flow such as is found near the jet stream is not included. Possibly even more critical information concerning variations at the surface boundary (i.e., SST) is missing; studies by Namias (1968) and others reveal that variations in SST have a strong effect on storm tracks and the general circulation. Without including at least some SST parameters, it would appear that analogs using only atmospheric parameters might evolve in entirely different manners.

The observed nonlinear behavior of the atmosphere concerns all analog systems. The interaction of the synoptic (SD) scale with the longer (SL) scale in a nonlinear fashion, well documented in the literature, can cause major changes in the SL scale not indicated in a historical analog sequence. Sanders and Gyakum (1980) stated, for example:

> "It is interesting and suggestive that this cluster of Atlantic bombs (intense SD minimums) was the prelude to a spectacular breakdown of the zonal flow over southern Europe, starting with wave amplification in the eastern Atlantic the last three days of this period and, during the days immediately following, culminating in a cutoff anticyclone over Scandinavia and cyclone over the Mediterranean Sea."

8.2 RECOMMENDATIONS

It is recommended that the Navy not continue development of IRRAS at this time. The same recommendation is made for the Silent Data Area project (described in Appendix A) which also uses the IRRAS historical data base.

If the problems dealing with the inadequacies of the data base can be solved, however, it might be worthwhile to continue development of IRRAS. The design of the IRRAS time funnel to use numerical model forecasts so as to expand capabilities for midrange prediction is especially promising.

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APPENDIX A

USEFULNESS OF IRRAS HISTORICAL DATA BASE FOR ANALOG-MATCHING IN SILENT DATA AREAS

A.1 INTRODUCTION

An analog-matching technique using the IRRAS historical data base to estimate the current meteorological conditions for any possible silent data area (ASDA) has been developed by NEPRF (Hamilton and Buenafe, 1980). The purpose of this study is to determine the availability of high-scoring analog cases from the historical data base. Without these acceptable analogs, it would be of little value to tune and verify the ASDA system.

A.2 METHOD

The procedure designed to test the usefulness of the IRRAS historical data base incorporated the following steps.

(1) Define a possible silent data area.

(2) Construct the regionalized IRRAS historical data base.

(3) Run IRRAS to pick best analog candidates.

(4) Compare analog candidates with verifying analysis.

A.3 DEFINITION OF THE SILENT DATA AREA

The silent data area should be constructed to include not only a normally rich data area, but also one which might suddenly become data-void. The area chosen for this experiment is bounded by latitudes 42°N and 70°N and by longitudes 26°E and 70°E, and includes essentially the western region of the Soviet Union (USSR). This silent data area, to be called USSR for the remainder of this paper, is shown in Figures A-1, A-2, and A-3.

A.4 CONSTRUCTION OF REGIONALIZED IRRAS HISTORICAL DATA BASE

The optimum sizes of regionalized bit-coded subsets for the silent data area are determined by the number of modules (described in Section 2 of the main report) required to depict the scale of motion -- i.e., SV, SL or SD -- relative to the size and location

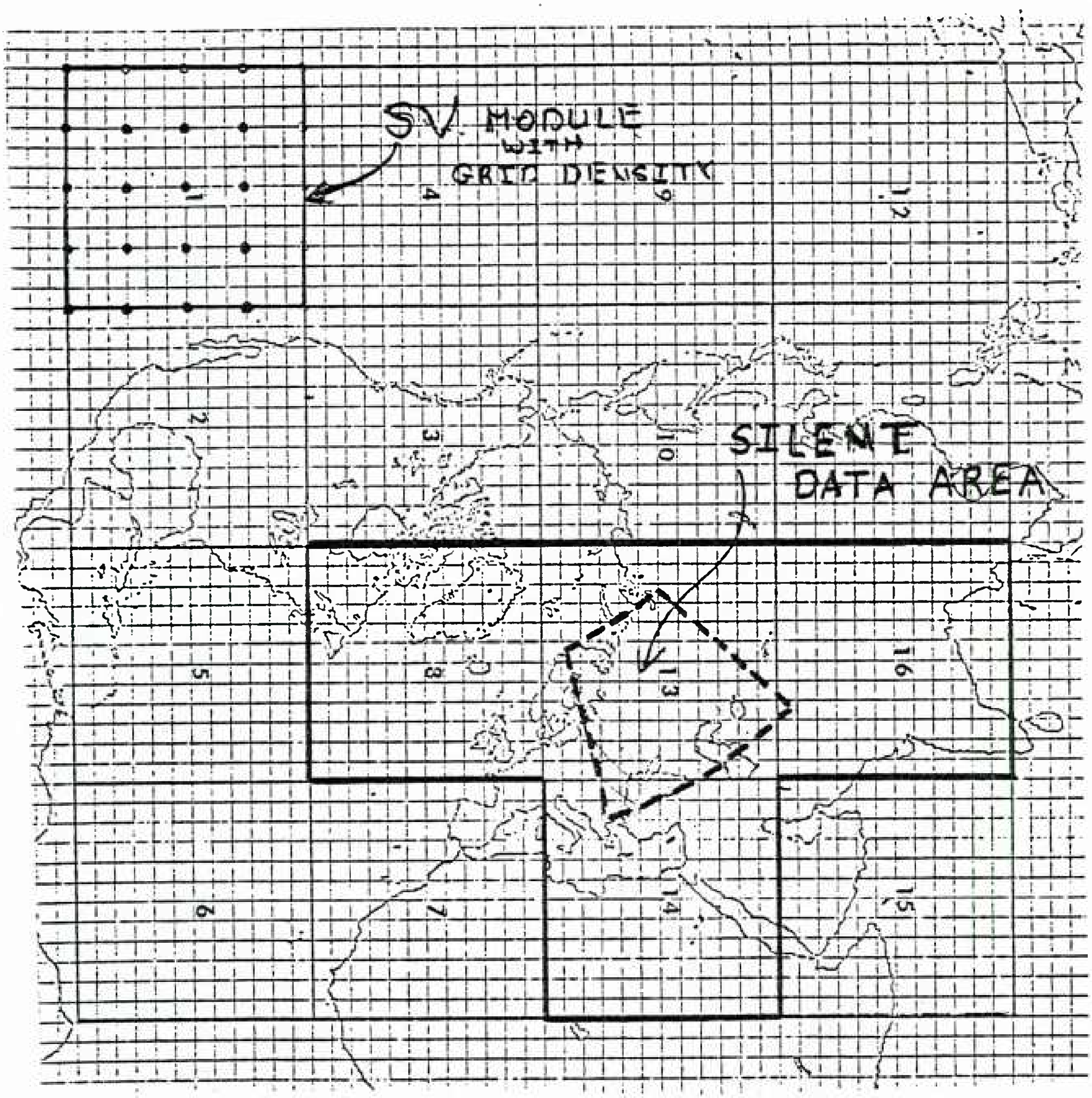

Figure A-1. Regional subset of IRRAS historical data base used to denote USSR silent data area: SV modules.

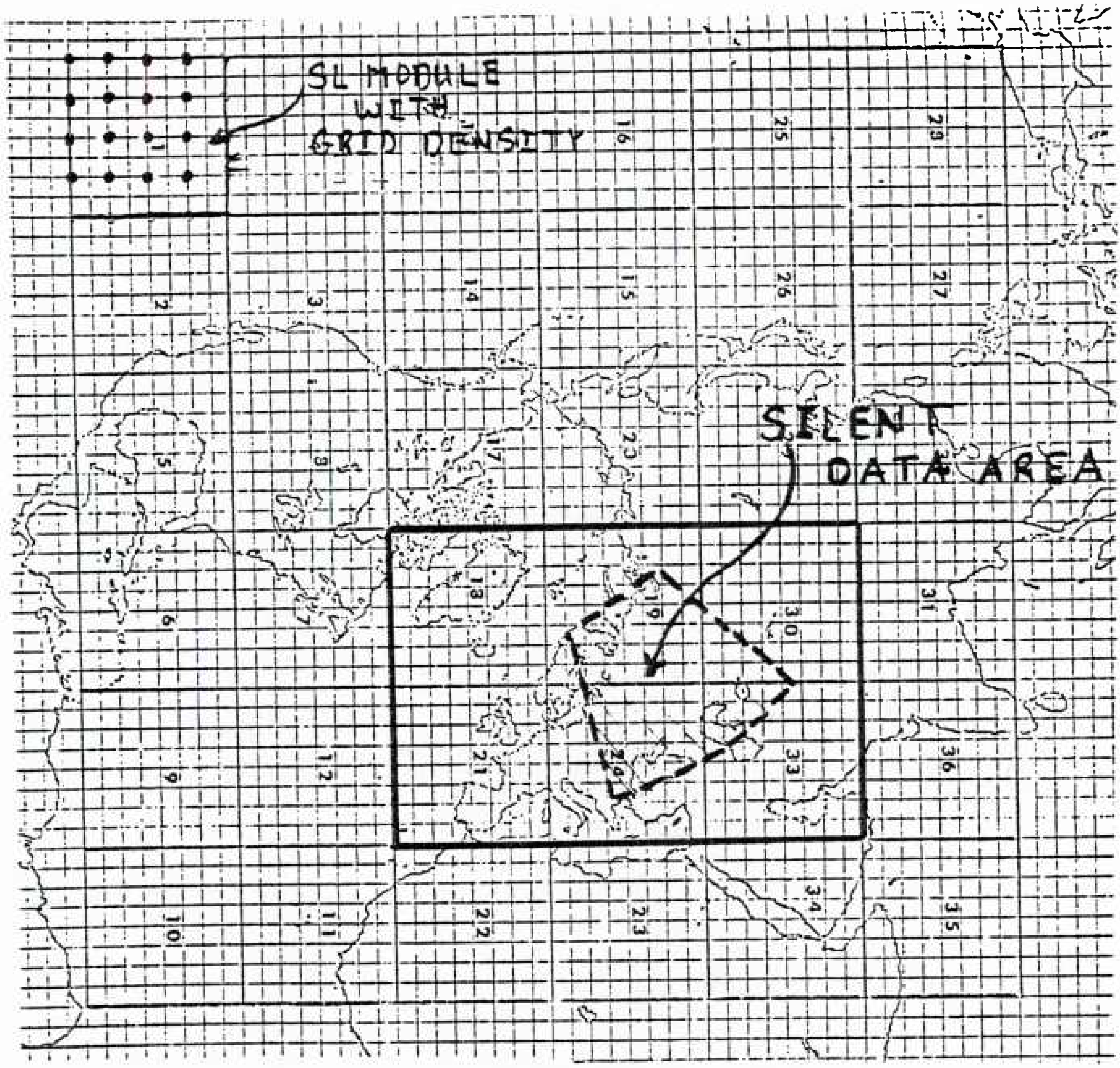

Figure A-2. Regional subset of IRRAS historical data base used to denote USSR silent data area: SL modules.

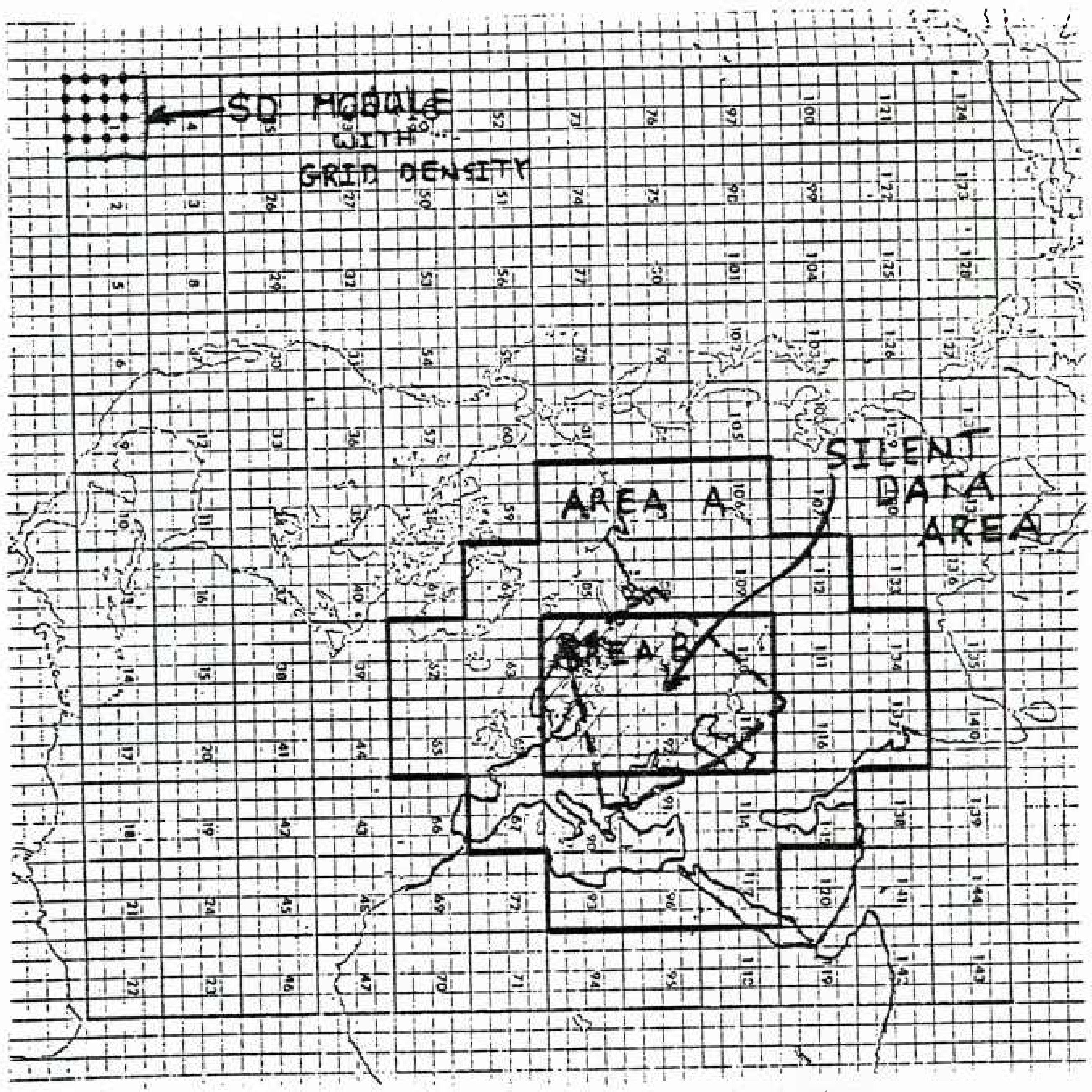

Figure A-3. Regional subsets of IRRAS historical data base, SD modules -- Area A used in USSR-PICK and Area B used in USSR-VERIFY.

of the silent data area. For the SV scale there should be at least four modules centered on the silent data area. The modules chosen for the USSR area are shown in Figure A-1. Similarly, for the SL scale, the modules should be centered on the silent data area and cover an area as close as possible to the SV area. Figure A-2 shows the six SL modules used for the USSR area. It should be noted that because of the relatively large size of the SV/SL modules compared with the USSR area and the slow time variability of these ranges-of-scale, all modules, even those included in the USSR area, are included within the area to be bit-coded.

The SD scale is treated differently from the other ranges-of-scale. SD, the smallest range-of-scale, varies the most rapidly thus making it the most likely to be incorrect within the silent data area. Therefore, SD modules that most closely coincide with the silent data area are omitted from the regionalized data base. The SD area is shown in Figure A-3, where the excluded USSR area in the middle is surrounded by a boundary approximately two SD modules wide.

The regionalized IRRAS historical data base, constructed for the modules shown in Figures A-1, A-2, and A-3 and for the 500 mb and 1000 mb levels and 500-1000 mb thickness, respectively, was made using procedures described in Caton (1979). The file used for picking analogs for the USSR area will be called USSR-PICK.

For verification purposes, a second data file is necessary. This file contains the same bit-coded data for the SL and SV scales as USSR-PICK. For the SD scale, however, only the modules for the inner hole shown in Figure A-3 are included; these are the modules which make up the silent data area. This file is called USSR-VERIFY.

A.5 ANALOG SELECTION PROCEDURE

A series of analog selection runs using IRRAS were made for the two data files, USSR-PICK and USSR-VERIFY. Since IRRAS was not being used to make forecasts out in time, the time funnel described in Section 5.1 was removed from the selection procedures. In other words, only the situation S at time t, shown in Figure 8, was used in making comparisons with situations in the historical data files.

The selection gates described in Section 5.2 were set in the usual fashion for the IRRAS-PICK runs so as to remove cases that were dissimilar from consideration. The SV scale gates remove cases from entirely different seasons, while the SL scale gates remove cases associated with entirely different longwave flow patterns.

The weighting factors used in the final selection process (see Section 5.2) were set to give full weight to the SD scale for both the 500 mb and 1000 mb levels and the 500-1000 mb thickness. The weighting factors for the SL and SV scales were set to zero. Thus the analogs picked by the final selection process from data file IRRAS-PICK depended entirely on the synoptic scale (SD), the scale most apt to be incorrect within a given silent data area.

For the IRRAS-VERIFY runs, the selection gates and weighting factors were set with the same values as with the IRRAS-PICK runs. The major difference between these two runs concerns the final selection process: for the IRRAS-PICK, the selection is made over the outer ring shown in Figure A-3; for the IRRAS-VERIFY, the selection is made only in the inner silent data area.

A.6 DESIGN OF THE EXPERIMENT

The basedays chosen for evaluation of the IRRAS data for the ASDS system are listed in Table A-1 and are at essentially one-half month intervals during 1975. The one-half month interval was chosen to keep the cases independent of each other. The year 1975 was chosen because of a 12-hr continuity available throughout that year. The 12-hr continuity was necessary because this experiment was designed to compare the best analogs chosen from IRRAS-PICK with persistence.

Table A-1. List of 22 basedays (times are 12Z) used in analog-matching for USSR silent data area.

1975

15 Jan	15 Jul
1 Feb	1 Aug
20 Feb	15 Aug
1 Mar	1 Sep
15 Mar	15 Sep
1 Apr	1 Oct
15 Apr	15 Oct
1 May	1 Nov
1 Jun	15 Nov
15 Jun	1 Dec
1 Jul	15 Dec

The method of comparing the best analogs with persistence was as follows. For a given baseday, IRRAS was run using selection gates and weighting functions as described in Section A.5, and data base IRRAS-PICK. As an example, a list of the top ten candidates for the baseday 12Z 15 May 1975 using IRRAS-PICK is shown in Figure A-4. The IRRAS scores are based on the SD scale at 500 mb and 1000 mb levels and 500-1000 mb thickness. These scores have been normalized so that a perfect score is 1000. Note that in the IRRAS-PICK run, patterns being scored cover the doughnut shape area outside the silent data (see Figure A-3).

For the same given baseday, a second IRRAS run is made using IRRAS-VERIFY data base which for the SD scale contains only the silent data area shown in Figure A-3. To determine how well the candidates chosen from USSR-PICK verify, one need only compare the scores of these same candidates in the USSR-VERIFY run with persistence scores.

In the example run for 12Z 15 May 1975 shown in Figure A-4, only two of the top 10 analog candidates (00Z 11 June 59 and 12Z 05 May 50) chosen from USSR-PICK appear in the list of the top 35 candidates chosen from USSR-VERIFY. More importantly, the three dates -- 00Z 15 May 75, 12Z 14 May 75 and 00Z 14 May 75 -- all have

IRRAS RUNS

USSR-PICK
(Top 10 Analog Candidates)

DATE	IRRAS SCORE
00Z 11 Jun 59	706
12Z 24 May 50	703
00Z 02 Jun 71	699
12Z 11 May 60	698
12Z 18 Sep 63	692
12Z 28 May 58	691
12Z 05 May 50	690
12Z 23 May 50	690
00Z 26 Sep 57	688
12Z 12 May 60	685

USSR-VERIFY
(Top 35 Analogs)

	DATE	IRRAS SCORE
	12Z 15 May 75	1000
	00Z 16 May 75	821
-12 hr →	00Z 15 May 75	807
	12Z 16 May 75	746
	00Z 30 May 71	735
-24 hr →	12Z 14 May 75	721
	12Z 27 Sep 71	709
	00Z 18 May 59	709
-36 hr →	00Z 14 May 75	708
	12Z 17 May 75	704
	00Z 17 May 75	703
	00Z 01 Jun 58	702
	12Z 30 May 71	698
	12Z 05 May 63	698
	00Z 05 May 75	698
	00Z 11 Jun 59	696
	12Z 29 May 71	696
	00Z 07 May 67	696
	12Z 07 May 67	693
	12Z 03 May 50	691
	12Z 18 May 59	689
	12Z 07 May 48	689
	12Z 07 Jun 70	689
	12Z 26 May 58	687
	12Z 23 May 67	685
	12Z 11 May 75	685
	12Z 05 May 58	685
	00Z 07 Jun 70	684
	00Z 31 May 71	682
	12Z 21 May 54	682
	12Z 10 May 63	679
	12Z 07 Jun 56	677
	00Z 18 May 75	677
	00Z 05 May 68	676
	12Z 16 May 53	676

Figure A-4. Example of IRRAS runs for baseday 12Z 15 May 75.

higher scores. Thus a 36 hour persistence forecast using the 00Z 14 May 75 analysis would have supplied a better candidate for the silent data area than any of the top 10 analog candidates chosen from outside the silent data area.

A.7 RESULTS AND CONCLUSIONS

Figure A-5 shows a comparison between persistence and the best verifying analogs from the top 10 candidates for a given baseday, chosen from USSR-PICK (example shown in Figure A-4, basedays listed in Table A-1). Of the best verifying analogs, only two actually beat the 12-hr persistence, while one half did poorer than 24-hr persistence, and three were not able to beat 72-hr persistence.

These results are extremely poor when one considers the fact that the SD scale varies rapidly with time -- with persistence only a good forecast out to 6 to 12 hours (see Section 5.2). As discussed in Section 8, a much more extensive data base for the SD scale would be necessary to find analog cases which might prove to be of value in filling in a silent data area.

It is therefore concluded that until there is a substantial improvement in the analog data base, the ASDA system should not be implemented.

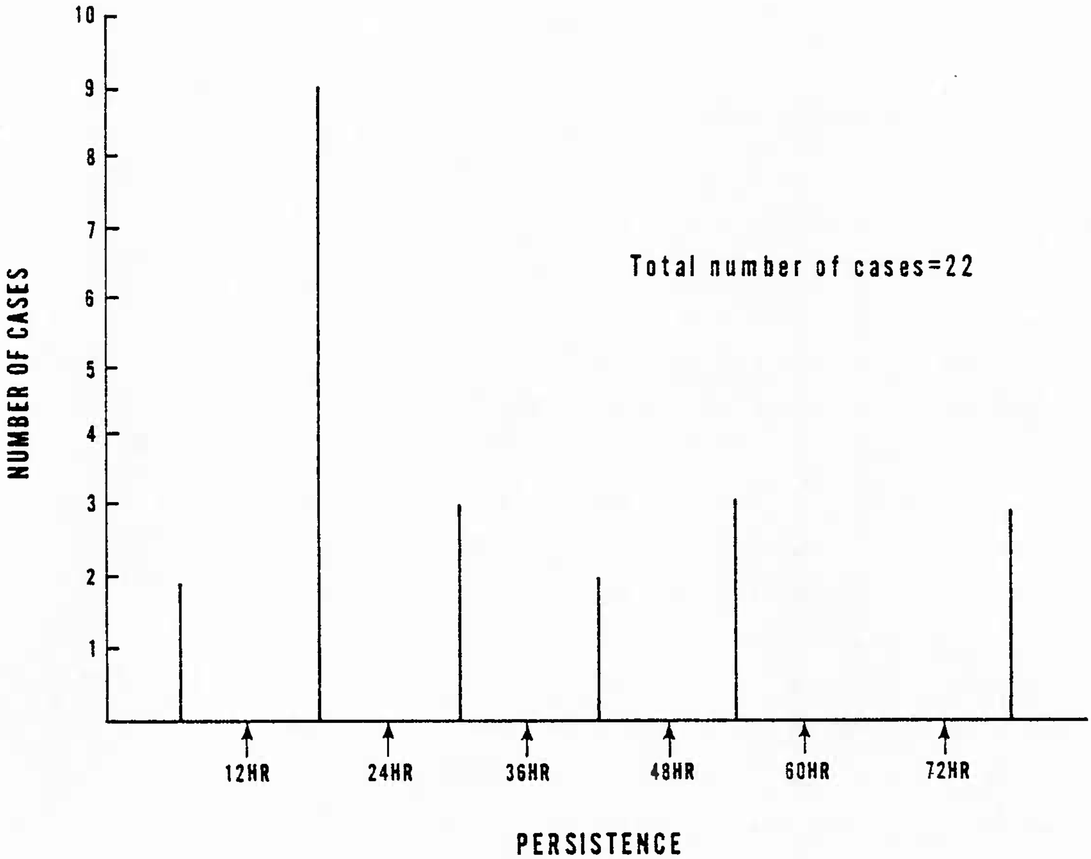

Figure A-5. Best analog candidates chosen from USSR-PICK, compared with persistence for the USSR silent data area.

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